THE

ONTARIO WATER RESOURCES

COMMISSION

INTERMEDIATE COURSE

FOR

WATER WORKS OPERATORS

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INTERMEDIATE WATER WORKS COURSE

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MAINTENANCE OF VALVES, LOSS OF HEAD GAUGES RATE OF FLOW CONTROLLERS AND OTHER MECHANICAL DEVICES AT WATER TREATMENT PLANTS

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In order to meet the system requirements, most water works operators find it necessary to use all of their equipment in their daily operation. Therefore, to avoid the embarrassment of water shortages, it is most necessary to keep all equipment operating properly.

Orderly maintenance and preventative maintenance is the cheapest insurance against costly equipment failure. Lack of this results in costly repairs and breakdowns to vitally needed equipment.

The prerequisites of good plant maintenance are:

1. A thorough knowledge of the equipment
2. Proper tools, and
3. Adequate repair parts

The knowledge of your equipment can be obtained from the instruction manuals issued by the maker of the equipment. Special tools for certain units should be obtained from the manufacturer and an adequate supply of properly sized common shop tools are needed for efficient maintenance procedures. Repair parts should be stocked according to the number of machines or equipment installed and the expected operating life of the equipment parts.

The amount of maintenance required to keep equipment operating efficiently can be minimized if routine maintenance is started at installation time instead of waiting for equipment failure or breakdown.

I am going to refer to routine maintenance by operators of equipment ordinarily found in most filter pipe galleries and plants. Equipment manufacturers usually supply procedures for maintenance jobs which are routinely done by the operator such as air purging, oiling, mercury weighing, calibration of instruments using mercury and water manometer check equipment.

Filter loss of head gauges, rate of flow gauges and rate of flow controllers normally have one thing in common and that is a mercury chamber. This is the most important part of their operation and therefore should receive the most maintenance and care. All the chambers have a supply of mercury -- so let's talk about mercury.

Mercury used in these chambers must be pure and free from other metals with which it amalgamates. If the mercury shows signs of sticking to the chamber parts, you have a pretty good sign of impure mercury and it should then be removed and washed in a shallow glass or plastic vessel. To wash, it first, use a concentrated solution of caustic potash, then a 25% solution of nitric acid and finally with distilled water. Never use galvanized or tin containers or funnels-use only glass, bakelite or plastic to avoid contamination of the mercury by amalgamation.

Operators handling mercury must always bear in mind the toxic effect of this element, an exposed surface of only 4 square inches under normal atmospheric conditions can produce a toxic concentration in a small work room in only a few minutes. Therefore, mercury should be handled only in well ventilated rooms especially during the washing or cleaning operation as normally large areas are exposed during this process. Mercury taken internally is extremely poisonous and destroys the cells of the kidneys; the antidote is whites of eggs. Spillage should be avoided and should be handled over trays with raised edges.

If mercury is spilled during a filling operation, the chamber should be thoroughly drained, the mercury reweighed accurately and the chamber refilled.

Most of the maintenance of a mercury meter will be in keeping the pressure connections tight and the meter body clean. Valves that come in contact with mercury should be stainless steel needle valves and not brass gate valves. Pipe lines must slope from the mercury chamber to the Venturi and some sort of a mercury trap should be installed in this line. Connections should be made on the side of the Venturi and not on the top or bottom; air could enter from a top connection and sand or grit from a bottom connection.

Most mercury chambers must be purged of air at regular intervals. This is usually determined by the accuracy of the metering equipment. If the gauge is not reading accurately, the mercury level and quality must be checked. If small drops of mercury are found around the mercury chamber meter, it is usually an indication of a leak and the mercury from that meter should be drained and re-weighed. The weight of mercury required is usually marked on the chamber. Therefore, an accurate set of scales should be available.

LOSS OF HEAD GAUGES

This gauge indicates, by direct reading, the loss of head through the filter bed. This is controlled by the movement of a float in a mercury chamber. The level of the mercury is controlled by the effective difference in head

between the water over the bed and that in the effluent line from the filter, by correctly designing the chamber, the movement of the float is directly proportioned to this difference. The movement of the float is transmitted to the gauge either by cables or by pneumatic transmission. The cables are usually phosphor bronze and should be inspected frequently and protected from corrosion with some protective coating such as vaseline or similar compound. The mud leg should be regularly cleaned to prevent sludge or silt from entering the mercury chamber.

RATE OF FLOW GAUGES

This gauge consists essentially of a differential producing device, usually a Venturi tube, which measures the flow of water and operates the mercury chamber. This chamber translates the differential pressure at the tube into a proportional movement which is transmitted to the gauge head and records the flow through the Venturi tube. The connections to the Venturi tube should be purged and cleaned periodically to keep scale and other foreign matter from closing the openings. Vent holes in the annular chamber may be kept clear by manually operated devices or by systems of continuous or intermittent flushing. If the vents and other connections are plugged, you are running a good chance of having an inaccurate meter. If heavy scaling conditions are encountered in the Venturi, it may be advisable to consider a Venturi by-pass and a means of descaling the Venturi throat.

RATE OF FLOW CONTROLLERS

The rate of flow controller regulates the size of the discharge opening, which, in turn, regulates the flow of water from the filter at a uniform rate, compensating for the loss in head through the filter. The controller is essentially a valve controlled by the rate of flow as determined by a differential producing device, normally a Venturi tube. This may be incorporated as one unit as in a mechanically operated balanced valve control chamber or by a butterfly valve actuated and adjusted hydraulically, pneumatically or electrically. In any case, it is normally placed after the Venturi. The reason for this being that if a filter run is continued until there is a negative head in the Venturi tube, air may be drawn into the pipe lines leading to the mercury chambers and unless lines slope so this air can be released back to the tube, the gauge may not be accurate. In a direct acting controller, air collecting in the top must be purged, sand or silt must also be purged from below the rubber diaphragm. Occasionally these diaphragms break and replacement is necessary. These must be handled carefully and the surfaces touching metal must be coated with a mixture of flake graphite and water. The valve stem leaving the valve must float through its gland or stuffing box of its own weight.

In the majority of cases, the Venturi tubes controlling the rate of flow controllers and rate of flow gauges are located in the filter pipe gallery, because of the excessive condensation prone to form in this area, external cleanliness is a must on these Venturi tubes as it is on other metering equipment located in these areas. Painting of the gallery with a moisture and mildew resistant paint prevents corrosion from starting. This also is an incentive to keep the plant clean and attractive. Insulation or lagging these lines has been used most successfully in reducing condensation and the resulting corrosion.

All controllers that use pilot valves should have some kind of strainer, cloth is most satisfactory, to catch the fine particles of grit and sand which could foul and wear the finely machined surfaces. When the flow through a pilot valve becomes fouled, the plug is removed from the strainer and flushed with clean water; if the strainer or cloth is damaged a new strainer must be installed. If it is found that water passes through the pilot valve without moving the control valve, it is probable that the trouble is in the controller hydraulic cylinder. The leather cups on the piston should first be checked. If water continues to pass through the pilot valve, it is an indication that the pilot piston and sleeve are drawn and worn. This calls for a complete replacement. If the controller maintains a higher rate than that set, it indicates that there is either a rupture or break in the diaphragm which must be replaced.

If the control valve is of the butterfly type, the rubber seats may require change when it is worn or damaged by some foreign object. The leather piston cups in the cylinders of hydraulically operated valves wear according to time and usage, and you will occasionally be faced with their replacement. When this is done, the cylinder walls should always be cleaned and polished so that new cups will not be scored and cause leakage.

PNEUMATIC SIGNAL TRANSMISSION

In many newer and later designed plants, signal transmission from the mercury chambers is accomplished pneumatically. This involves an air supply normally in the form of a compressor which is electrically driven but usually has an emergency source of power such as a gasoline or diesel engine which may be started either manually or automatically in case of power failure. The prime source of trouble in such a system is moisture. Moisture must be kept out of the system at any cost. The presence of moisture cannot be prevented but it can and must be kept out of the system. The place to start is at the compressor, all water must be blown out of the air storage tank at least daily. The supply lines leaving the receiver usually are fitted with an air filter and another water separator. These should receive the same attention as your storage tank-blow it daily. In some cases, it may be necessary to install refrigeration equipment to remove even more moisture from the

system. If the system is not working satisfactorily after all checks have been made and precautions taken to remove any moisture, check the supply. All regulators should be checked for moisture and to see that the correct air pressure is being maintained, then check all joints for leaks fittings or places where vibration or wear could cause tubing or piping failure. This is simply done with a soap and water solution watching for bubbles. It is also a good idea to check the diaphragm chambers of the air positioners or for clogging of the air escapement ports.

When using a controlled air pressure converter and operating problems are encountered...the water lines from the filter or Venturi should be checked. These lines some times become clogged and therefore should be flushed until clean. All air should be vented from the water chambers of the converter periodically. When venting this air, the vents should never be opened until the controller valve is closed, otherwise air may be drawn into the line instead of expelling it.

The calibration of a rate of flow converter, a loss of head converter or any other pressure differential converter is a tricky proposition. Reference should be made to the manufacturer and the correct calibration chart, gauges and regulators used. Incidentally, a small amount of fine machine oil on the gear trains in gauges reduces friction and possible error in calibration. The gear trains should be cleaned of lint or other foreign matter before oiling. Meter bearings should receive the same treatment. A special oil can usually be obtained from the manufacturer or they can give you a recommendation as to the type of oil to be used.

VALVES

Your plant is equipped with a multitude of valves but they will probably fall into three or four categories; gate valves, globe valves, butterfly valves, diaphragm valves, needle valves, plug valves and penstocks. Some you may have several of, some you may have none of. In practically every type of valve with the exception of possibly the penstock, there is one thing in common, that is, a stuffing box or gland around the valve stem. The packing of this stuffing box or gland is an important feature of good plant maintenance. A leaking valve cannot only cause trouble in the valve, but will contribute to difficulty in general housekeeping. I doubt very much as to whether you will ever get two maintenance men or operators to agree on the details of how to repack a gland, although most will agree on the following suggestions for repacking a gland in a general way:

1. All old packing should be removed from the gland.

2. Packing must be kept clean during installation because the valve stems and rods can be scored from grit or dirt picked up by the packing.

3. The stuffing box on the stem should be thoroughly cleaned after the old packing has been removed and kept clean during the repacking operation.

4. The correct size of packing should be used-this can be determined by checking the diameter of the valve stem and the inside diameter of the stuffing box. There is a definite reason for this, oversize packing is difficult to install and may cause excessive friction. Undersize packing may be ruined by too much take-up. All new clean packing should be used, old packing may be dry, highly compressed or distorted, have high friction and may be contaminated with dirt or grit and lead to scoring of the stem.

5. A length of packing should never be wound into the gland and only ring form should be used.

6. A ring from the packing should be cut, by using either the shaft or a mandrill of the same size as the one on which the packing is to be used, in order to get close fitting rings.

7. Sharp clean cuts should be made, fraying on the ends of the rings should be avoided.

8. All packing ring joints should be cut to a snug fit, making the ends meet with a butt or level joint.

9. Each ring should be carefully seated before placing the next ring in the box.

10. All rings should be installed so that the joints are staggered and kept at least 90° apart. As a tip, always place your packing rings with the joints staggered in a clockwise direction to make it easier to locate them when removing the packing at a later date.

11. The follower should be pulled up sufficiently tight after re-packing to ensure final seating of the new packing. The gland nuts should be backed off to relieve excess pressure and then adjusted to operating conditions. Some operators cut an extra ring and keep it near the gland, carefully wrapped to prevent soiling, so that an additional ring may be quickly slipped in if required at a later date. A word of caution - use the right packing in the right place for the conditions under which the packing is to be used. I would suggest your consulting the packing manufacturer and get his recommendations. When

old packing is removed, always use the proper tools as otherwise the box or stem or both may be scored making a tight gland impossible. You are all acquainted with the common gate or sluice valve and know that seat rings and wedge surfaces may become scored or even eroded either through water action or corrosion. In the larger valves the seat rings can be unscrewed or unbolted and removed through the bonnet of the valve, the seat ring may be trued on a lathe or lapped with a lapping compound. If heavily scored, replacement may be necessary. This same treatment is applicable to swing check valves. While the valve is apart, check stem and clean and polish this if necessary. When this is accomplished it will be necessary to reassemble the valve and sheet packing will be necessary, not only on the bonnet joint, but probably on the valve flange connections. A heavier sheet packing than necessary should never be used, the thinner the gasket material the better. Here again the correct type of gasket material should be used. Ring gaskets are preferable to full face gaskets if the flanges are heavy enough to prevent distortion. Great care should be used when it is felt necessary to use gasket dopes. Oil or grease should never be used on rubber or rubber compound gaskets. Graphite and water or glycerine may be used. Dope should never be used on both sides of a gasket; it may cause slippage and blowout. All valves should be operated at intervals through their full range open to shut or shut to open. This will not only assure the operator that the valve is operable and not stuck, but will also tend to flush out any sediment or debris which might be in the valve.

You may or may not have plug valves in your plant, but these valves can give you nothing but trouble if not maintained and inspected regularly. We have found that the best way to maintain them is to use them. They have a tendency to jam or freeze due to their very design. Most of them are wedge or conical shaped and to keep them tight, a considerable tension must be put on the plug. Frequent operation will break any tendency for the closely fitted surfaces to corrode together. Most of them have some system of force lubrication either by stick lubricant forced in the top by a screw or a fitting to take a grease gun. Pressure exerted by the lubricant tends to lift the plug from its seated position and allow easy rotation. However, the best way of assuring yourself that the valve is operable is to operate it. A frozen or stuck plug valve when you need to open or close it is trouble of the first order.

Needle valves appear quite frequently and should be frequently lapped in to assure efficient operation and control.

Foot valves on pumps can be troublesome and may be difficult to maintain due to their inaccessibility. Most of the trouble will present itself in a loss of suction of your pump due to its losing its prime. Most foot valves are of a flap valve type with a metal to metal seat or a metal to composition seat, with the flapper hinged at one point. This hinge, due to sand, grit or sediment, may stick with the valve in an open position. This can be serious if you do not have some auxiliary priming system available or a means of letting main water back to the pump. If this is the case, the foot valve must be removed, the hinge section freed and cleaned and probably the seat adjusted or dressed. A stuck foot valve may sometimes be freed by bumping it with the pump. That is, starting and stopping it rapidly so as the weight of the water tends to jar the valve loose.

AUXILIARY DRIVES

Many of the plants have auxiliary drives either in the form of a diesel engine or gasoline engine driving a unit such as a compressor, pump or alternator which may either be manually or automatically started in case of power failure or as a means of reducing peak electrical demands or as a fire pump for the system. Manufacturers' instructions and their maintenance manuals should be carefully followed in maintaining these units. In general, however, they should be started regularly and operated until normal operating conditions such as temperature, oil pressure, etc. are reached. If the unit is equipped with a starter, the battery should be regularly inspected and checked. The battery may have its own trickle charger attached to maintain the battery charge. Special care should be exercised with this unit. A too high charging rate may burn out your battery making the engine difficult to start. We have found it expedient to discard or disconnect the charger in some of our plants and rely only on weekly or semi-weekly checks of the engine to maintain the battery charge. If the engine and battery are in good condition the battery will recharge itself during operation and hold the charge until required again. In isolated unheated pump houses attention must be given to the provision of anti-freeze in radiator cooled auxiliaries. If right angle drives are used attention should be given to the reverse spin stops; in some instances, grease has been used to hold drop pins or balls when assembling the unit, the pins will often stick and the purpose of the device is defeated. Clutch and universal assemblies must be regularly inspected and serviced. A grabbing clutch can cause a great deal of damage and, if it does not release, further damage can be done to the auxiliary drive. On automatically

started equipment a time delay device should be incorporated in the control circuits to prevent the unit starting too soon. The delay in starting should be of the order of 15 to 30 seconds otherwise your engine may be trying to start at the slightest power flicker.

PUMPS

I am not going into all the ramifications of pump maintenance as this has either been covered by others, but it is necessary to point out the importance of correct and accurate pump and drive alignment. Alignment of units should be checked frequently. This relatively simple procedure will, in many cases, point out the possibility of corrective maintenance on bearings, shafts and seals on the unit itself. You have probably all noticed that some pumps seem to operate better under certain temperature conditions. This can be attributed to pump alignment. Pumping units are usually set up to very close tolerances and these settings may change due to the physical temperature of the pump. Casings, bed plates and shafts will all vary slightly in size due to temperature, inside temperature, outside temperature and temperature of the water. A sudden drop in water temperature may seriously affect alignment tolerances.

MICROSTRAINERS

A microstrainer is essentially an open drum covered with a very fine stainless steel fabric rotating under controlled conditions and with a means of constantly washing the fabric covering. In the water works field it is primarily used as a raw water conditioning device but in some cases has been used with chlorination as the only treatment. They are primarily used for algae control and they cannot be relied upon for turbidity removal. There are not many in use but more and more installations are being made. Relatively few of you have them but the maintenance problems associated with them may be of interest. These problems are many and the operator having one or several must maintain constant supervisory control over them. In operation, raw water passes through the fabric from the inside to outside, as the strainer is rotated, a constant washing action is provided through a series of fan shaped sprays on the outside, washing algae or other small solids into a trough located in the interior of the unit and so to waste.

The unit itself must be installed in strict compliance with the manufacturers' specifications otherwise abnormal head differentials may be set up between the interior and the exterior of the strainer and the fabric may become strained and overstressed resulting in pinholes

and eventual tearing. Operating speeds and wash water jet pressures should be varied as per manufacturers' instructions.

In spite of the care and supervision exercised on these units, certain conditions of raw water may cause operating troubles and possible blinding of the fabric. This normally results from a slime condition coating the fabric. "Shock" chlorination cleaning is then used. This treatment consists of lowering the water level in the strainer chambers to about 4" and the spraying of the fabric after the jets have been shut off with one gallon of 12½% sodium hypochlorite. The drum is then rotated at slow speed for about 15 minutes and the jet wash applied at full pressure and the chambers drained to waste. Under no conditions are bleaching powders to be used as these may block the fabric apertures.

In all respects a microstrainer should be treated as a delicate instrument, manufacturers' instructions relating to installation, lubrication, cleaning, starting, stopping, and operation must be followed exactly, slam-bang; ham handed operating practices must be forgotten and care and vigilance exercized.

FLUORIDATION

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INTRODUCTION

In this paper we will consider the subject of fluoridation from the point of view of the operator who is charged with the responsibility of operating the equipment properly to provide the required fluoride dosage and to take the necessary precautions to safeguard his own health from the toxic effects of the fluoride compounds during the execution of his duties at the water works. These notes should also be of assistance to persons planning to install a fluoridation system.

DEFINITION

Fluoridation is the adjustment of the fluoride content of a public water supply to approximately 1.0 ppm. The permissible operating range is 0.8 - 1.2 ppm.

Most surface supplies have little or no natural fluoride content. Deep wells in Ontario range from as little as 0.1 ppm to a high of 2.2 ppm. Many well supplies, therefore, do not require fluoridation, whereas many need the addition of only a small amount of fluoride.

BASIC INFORMATION OF FLUORIDE CHEMICALS

At the present time there are three compounds which are being used in Ontario, viz. sodium silicofluoride, sodium fluoride and hydrofluosilicic acid. Other compounds such as calcium fluoride (fluospar), magnesium silicofluoride, ammonium silicofluoride and potassium fluoride are also available and are being used in certain specific applications in the United States.

Fluorine as a chemical element, does not exist free in nature. Fluorine is now being manufactured and is available in large quantities as a gas. However, its cost and the extreme hazards associated with its handling will at present make it unsuitable as a water fluoridating agent. Table I appended, illustrates the characteristics of the fluoride compounds in use in Ontario.

COST CONSIDERATIONS

Based on fluoride content, sodium silicofluoride is the least expensive source. Sodium fluoride is about two and a half times as costly, while 30% hydrofluosilicic acid is about three times as expensive. These cost comparisons are based on the fluoride requirements for an average-sized plant. However, the volumes purchased, and the distance from the source of supply along with in-plant considerations, may rule that the acid is the preferred chemical to use.

EQUIPMENT

Feeders

Fluoride feeders should be designed for the maximum instantaneous pumpage at the source of supply, excluding extremely high pumpages experienced during fires, hydrant flushing etc.

Dry feeders of the volumetric or gravimetric type may be used. Volumetric feeders have to be equipped with a weigh scale and preferably equipped with a weighing mechanism and a loss-in-weight recorder. Solution feeders should be of a positive displacement type.

Feeder Control

Feeder controls can be either manual or automatic. Manual control can be very accurate under ideal conditions, but is requires constant vigilance and a high order of skill. Automatic control, on the other hand, generally results in more accurate feeding.

Manual Control is obtained by adjusting the feeder by hand, usually as the result in a change in the quantity of water to be treated. However, many other causes for a change in fluoride level may arise. These include changes in the purity of the

fluoride compound, changes in the dissolving characteristics of the chemical and changes in the fluoride level in the raw water. This system is used frequently in the larger water plants where adequate analytical laboratory services are continuously available and where expert operators are constantly in attendance for adjusting feeders.

Two systems of automatic control are available. The pacing system is based on an adjustment of the feeder automatically, depending on the quantity of water to be treated. The other system of automatic control is based entirely on the fluoride level in the treated water. This, of course, requires the continuous automatic analysis of fluoride in the treated water and a means for adjusting the feeder to maintain a constant pre-set fluoride level. The latter method can be used to provide a continuous record and a graphic history of fluoride concentrations in the water.

<u>Hoppers or Day Tanks</u>

Hoppers and day tanks should be designed to hold one day's requirements.

<u>Dissolving Chambers</u> (for Dry Feeders)

Dissolving chambers should be provided in all cases. In order to obtain continuously a solution of a dissolved fluoride compound from a dissolving chamber, it is advisable to limit the maximum solution strength to one-quarter of that of a saturated solution. This is based on a minimum detention time of five minutes in the dissolving chamber. In practice, dissolving chambers are seldom made with less than five U.S. gallon capacity. This size would be sufficient to dissolve sodium silicofluoride at the rate of 1 lb. per hour or 24 lbs. per day. If sodium fluoride were used, five times as much chemical could be dissolved in the same size dissolving chamber.

The water supply to the dissolving chamber should be metered. Too much water reduces detention time and, therefore, reduces the opportunity for the chemical to dissolve. Too little water will increase solution strength and, therefore, reduce the speed at which the chemical dissolves.

From Table I it will be noted that the solubility of sodium silicofluoride varies considerably with temperature. Since this chemical is more soluble at the higher temperatures, it would be reasonable to assume that increasing the temperature of the water, by heating, would be a distinct advantage. However, it has been found that the rising vapours from the dissolving chamber moisten the chemicals in the hopper and cause them to clump together and to adhere to the feeding mechanism. These problems affect the accuracy of the feeders. For this reason, this method of increasing the solubility of sodium silicofluoride is seldom used.

If the chemical is not being completely dissolved, check the following:-

1. Dissolving chamber too small - minimum size - 5 gallons.
2. Detention time too short - minimum time - 5 minutes
3. Too little water is being provided - check water supply by metering.
4. Insufficient mixing - provide water jets or electric mixers.
5. Short circuiting - provide baffling.

Corrosion-Resistant Materials

You will note from Table I that the pH of the saturated solutions of sodium silicofluoride and hydrofluosilicic acid is 3.5 and 1.2 respectively. The pH of the saturated solution of sodium fluoride is 7.6. This means that it is essential to provide corrosion-resistant materials when handling both sodium silicofluoride and the hydrofluosilicic acid. Table II appended, summarizes the corrosion-resistance of various materials.

TYPES OF INSTALLATIONS

The best installation may be defined as one that has the best combination of the following factors:-

1. Simple mechanical feeding device, either liquid or dry.
2. Simple piping or injection arrangements.
3. Minimum chemical handling.
4. Minimum maintenance and operational duties.
5. Means for maintaining a reliable permanent record.

Basically, there are two kinds of systems:-

a) Solution Feeders - feeding hydrofluosilicic acid or a solution (preferably saturated) of sodium fluoride by gravity or under pressure.

b) Dry Feeders (volumetric or gravimetric) - feeding sodium fluoride or sodium silicofluoride to a dissolving chamber before discharge, by gravity or under pressure, to the water supply.

We will consider eight different feeding arrangements. The five conditions mentioned above must be considered in evaluating the suitability of these systems for any particular plant.

1. Proportioning pump, delivering hydrofluosilicic acid by gravity directly from the acid container, on scales to point of application. This type of installation requires minimum chemical handling. A single unit proportioning pump can treat up to 40 mgd with 1 ppm of fluoride.

2. The same installation as above, with dilution of the acid with water.

   Dilution of the acid with water is sometimes necessary at some small water plants because of the limitations in accurate delivery of chemical solution feeders when set at very low rates. If an excess of free silica occurs in the hydrofluosilicic acid, a visible, insoluble precipitate forms when the dilution ratio is less than 20 to 1. This precipitate clogs pumps, valves, pipelines and other fluoride feeding equipment. It has been found that the addition of small amounts of hydrofluoric acid to the hydrofluosilicic acid will prevent the formation of this precipitate, which is finely divided silica. The amount added is in the range of one gallon hydrofluoric acid (48%) to 50 gallons hydrofluosilicic acid (30%). The optimum ratio depends on the quantity of colloidal silica which must be dissolved. This is best determined by the manufacturer. In the interest of safety at the water plant, and for maximum effectiveness, manufacturers should stabilize the acid by adding the optimum quantities of hydrofluoric acid.

The dilution requires accurate measurement of both the acid and the dilution water. The necessity for these measurements contributes to possible errors in the strength of the resulting mixture. By and large, when small plants are involved, it is more economical and easier to use sodium fluoride solutions obtained from a saturator. This will be discussed under point 4.

3. The same installation as above, delivering against pressure. If calcium and magnesium are present in excessive amounts, they may deposit on and clog the injection nozzle, thereby further complicating high pressure injection. Pressure feeding always involve additional equipment and more expensive maintenance than is required by gravity feed.

4. Proportioning pump for sodium fluoride using a saturator and feeding by gravity or under pressure.

   Saturators have many advantages. The constant solubility of sodium fluoride assures a uniform concentration over a wide range of temperatures. Water for the solution is automatically added to the tank by means of a float valve. As the water trickles through the bed of crystalline grade (20 to 40 mesh) sodium fluoride, a solution of 4% constant strength is produced. A sand bed on the bottom of the saturator provides a positive barrier between the crystalline sodium fluoride and the solution outlet. The saturator may be placed at a low level to facilitate filling and may hold a comparatively large amount of chemical. An entire 100 lb. bag may be added at one filling.

   If hard water is encountered (hardness exceeding approximately 75 ppm), the saturator make-up water must be softened, thereby complicating the installation and increasing maintenance.

   A saturator, with a proportioning pump of a 7.5 gph capacity, using 4% solution, will treat 3 mgd with 1 ppm of fluoride.

5. A proportioning pump for feeding 3 to 4% sodium fluoride solutions by gravity or against pressure.

   This involves careful weighing of the chemical and measuring of the make-up water to be used in the solution drum to determine the strength of the fluoride solution obtained. This creates problems similar to the ones raised in point 2.

6. Dry feeder (volumetric on platform scales or gravimetric) with dissolving chamber, delivering sodium fluoride or sodium silicofluoride solution, by gravity, to the point of application.

   Dry feeders are ordinarily used in most medium and large-sized plants or wherever gravity feed can be used. In Ontario, the majority of the installations are of the volumetric feed type.

   Volumetric feeders will deliver as little as 3 to 4 ozs. per hour to treat supplies of 200,000 gpd or greater. Gravimetric (weighing) dry feeders will feed as little as 1 lb. per hour, but are generally used for rates of more than 5 lbs. per hour or to treat supplies of 5 mgd or greater.

7. The same installation, as above, equipped with ejector or pump to deliver against pressure.

   If hard water is encountered, ejectors or pumps should not be used for rates which exceed approximately 12 to 20 lbs. per day of sodium fluoride. Ejectors or pumps will clog excessively with calcium or magnesium fluoride unless dissolver water is softened or a sequestering agent is used.

8. The same installation, as in cases 4, 5 & 6, equipped with a float controlled suction box to feed into the suction side of a pump.

   When a fluoride solution feeder is designed to discharge at a lower level or into the suction side of a pump, an air gap or a float controlled suction box should be provided. Without such a device to prevent siphoning of fluoride solution through the solution feeder, **gross** inaccuracies in the fluoride level in the treated water **are** possible.

POINT OF APPLICATION

Almost every water supply presents a different problem, sometimes involving a compromise between what is considered the best point of application and the best location for the chemical feeder.

In general, fluorides are applied most effectively at that point where the risk of losing them in a subsequent treatment is least.

The conventional application point for fluoride solutions is in filter effluent lines or in the clear well. At small plants using well supplies, and pumping stations, it is usually found advantageous to inject the solution into the discharge side of the pump. It should be noted, however, that it is a definite advantage to be able to permit the liquid fluorides from the dissolving chamber of a dry chemical feeder to flow by gravity into the clear well or open channel. This generally requires that the feeder be located above and in close proximity to these structures.

Fluoride should not be added with or before coagulants or with softening chemicals. As much as one-third of the applied fluorides may be removed from the treated water when the alum dosage is 100 gpm. In a few instances, it is economically justifiable to realise some loss of fluorides. Where transportation, storage or handling costs of the fluoride compound can be substantially reduced by adding fluoride to the raw or partially-treated water, the loss of fluorides through the plant may not be a significant factor.

Chlorine, chlorine dioxide or chloramines can be added anywhere in the plant or distribution system. There are no known reactions between fluoride at 1.0 ppm in water and the compounds formed in water after chlorination.

Even though a well supply is not chlorinated, the addition of a fluoride solution would not ordinarily provide a source of bacteriological contamination of the supply. Sodium fluoride solutions, for instance, are germicidal at only 5,000 ppm (0.5% as sodium fluoride) and most such solutions are prepared considerably stronger.

CHECKING RATE OF FEED

Good engineering requires that means be provided to check the feeder accurately for the amount of chemical being delivered.

Provisions for continuous testing are quite inexpensive and simple to provide that they should not be omitted. This operation provides a means of keeping necessary records and more closely controlling plant operations.

If hydrofluosilicic acid is pumped by a proportioning pump to the application point, the original acid container can be placed on a platform scale and loss in weight read at convenient intervals.

Loss-in-weight type gravimetric feeders have built-in scales that control the feed rate. Chart records can easily be attached to gravimetric feeders. Volumetric feeders can be provided with a loss-in-weight indicating and recording scale head.

If sodium fluoride solutions are to be pumped or measured by any other type feeder, several simple methods of continuous testing may be used. The simplest is a scale attached to the inside of the tank that can be easily read by the operator, although, for a deep tank, a float, cable, pulley and scale on the outside of the tank would be better. A sight glass will show the level in the tank at all times and, if connected to the tank and pump, will serve as a test gauge to show how much the pump is delivering with each stroke.

By providing an accurate water meter on the make-up water supply to a sodium fluoride saturator, a record of the sodium fluoride used may be kept.

Dry feeders for low rates of feed should be placed on a platform scale, as described above for acid tanks, and vernier indicators used to check the feed at low rates.

Dissolvers should not be on the scales of small feeders for two reasons:-

1. When feeding a few ounces per hour, the slightly fluctuating water level in the dissolver makes loss-in-weight tests unreliable, except for long runs.

2. Condensation on the dissolver increases in humid weather and runs down upon the scale thus increasing the weight on it.

Large dissolvers used for higher feed rates would also not be placed on scales because of their great weight.

INCRUSTATION OF FEEDING EQUIPMENT

Incrustants form occasionally in solution tanks, feeders and feeder lines. If excessive amounts of calcium or magnesium are present in the solution water, calcium fluoride or magnesium fluoride will settle out and become lost. Scale formation may be prevented by softening all the water used to convey the sodium fluoride solution or by treating it with a sequestering agent such as Calgon or Nalco 918. The sequestering agent required is a function of water volume as well as chemical characteristics, although the relationship is unknown and can be determined only by trial and error. Experience indicates that treatment may range from 7 ppm to 15 ppm. On the other hand, there is very little additional labour involved in removing the precipitated fluorides from solution tanks, inasmuch as sodium fluoride contains insoluble material which also must be removed periodically.

Generally, it has been found that sodium silicofluoride is not scale forming. Calcium and magnesium do not readily precipitate at low pH values.

Although hydrofluosilicic acid does not combine with the chemicals in the water to form a scale or precipitate, it can play other tricks with the water works operator. Hydrofluosilicic acid is a liquid and is fed as a liquid. Frequently, it is desirable to dilute it. Generally, this can be done without difficulty, but sometimes a silica jell forms which clogs strainers. As discussed previously, this can be overcome by notifying the manufacturer, who can correct the trouble by a slight change in formulation.

TUBERCULATION IN MAINS

Depending on the composition of the water, tubercles are sometimes formed on inside of pipes over pitted areas - they consist of mounds of the product of corrosion. It has been shown that fluorides and other anions from the water can become concentrated in these tubercles by means not clearly understood. The tubercles are very hard and quite insoluble in water.

An AWWA panel considered this matter in 1957, and reached the following conclusions:-

1. Fluoride ions may concentrate in tubercles in small amounts together with other negative ions such as sulphates and chlorides.

2. The rate of concentration of these materials is so slow that the amount of fluoride removed cannot be measured by the usual test methods.

3. There is no way in which the fluorides concentrated in the tubercles can be re-mixed with the water so as to bring about a measurable increase in fluoride content.

TOXICITY OF FLUORIDES

About 230 mg. of fluoride would have to be ingested to create sublethal toxic effects. Assuming that 2 liters of water are consumed by an individual each day, the toxic amount would be equivalent to 115 ppm fluoride in potable water. This is equivalent to a dose of 1150 lbs. of fluoride ion per million gallons. The lethal dose of fluoride ion is about 4 grams. Thus, again assuming the consumption of 2 liters of water per capita per day, this would be equivalent to the addition of 2,000 ppm fluoride or about 23.4 tons of 95% sodium fluoride per million gallons, far beyond the capacity of the chemical feeders used.

In the case of an operator being exposed to an excessive amount of fluoride, a physician should be called immediately and the following antidote applied.

Give a tablespoon of salt in a glass of warm water and repeat until vomit water is clear. Precede by lime water or 1% calcium chloride solution, if available. Give strong tea or coffee or a teaspoonful of aromatic spirits of ammonia in water.

Let us hope that none of us will have to go through this. It should never be necessary if you follow the few basic safety practices given next.

SAFETY MEASURES

The hazards inherent in the handling of fluoride by water works personnel can be eliminated by utilizing four safeguards:-

1. Choice of fluoride compound
2. Proper handling procedures.
3. Personal protective devices.
4. Dust collecting apparatus.

The inhalation of fluoride dust is the principle hazard to operators. This can be minimized considerably by using a recently developed crystalline sodium fluoride and other granular forms which contain practically no particles small enough to form dust. Careful handling of the powdered compounds, either while emptying barrels or when transferring small quantities from the shipping containers to solution tanks, is most important.

The operator should follow all instructions as provided by the manufacturer. Spilt fluorides should be removed by wet mopping. Masks should be worn to protect operators in the event dust is accidentally generated. Rubber gloves should be worn because fluorides are a skin irritant. Body surfaces exposed to fluoride dust should be washed thoroughly with water. Where large quantities of fluorides are dumped into feeder hoppers from barrels or bags, blower operated dust collectors should be installed in the hoppers. Pneumatic conveyors should be vacuum operated.

Present practice in water treatment plants is to obtain equipment permitting the fluoride feeder hopper to be filled no oftener than once a day. If reasonable care is used in handling the fluorides so as to produce the least dust, little danger to the operators is involved.

For a small plant the proper design of the hopper or loading door will permit placing the entire container within the hopper to allow the bag or drum to empty itself after the door is closed.

Actually, the greatest hazard occurs in the larger plants, where the fluorides are dumped from a barrel into a hopper opening which is at floor level. Occasionally, the fluoride arches in the barrel and then suddenly emptying, throws the cloud of dust into the air. In such installations, the dust exhaust system should be made part of the hopper equipment.

Of the available materials, hydrofluosilicic acid is by far the least hazardous. There is, of course, no dust for employees to breathe and there is no occasion, with a properly vented installation, for employees to breathe any fumes whatsoever. In case of a break or spillage one might breathe the room atmosphere for considerable periods of time without harm. The material is not harmful on the skin if washed away within a reasonable period. Rubber gloves, goggles and rubber aprons should be used when handling drums. In one case, in Philadelphia,

a leak in the pressure discharge of a pump squirted the 26% material full in the eyes of a mechanic. His eyes were washed with water, and he was taken to hospital where they were again washed, the treatment being repeated the following day. No ill effects have ever been evidenced.

CHEMICAL STORAGE

The storage of chemicals should be in close proximity to the feeder. The chemical should be stored in a reasonably dry room, not directly on a concrete floor. Bags and even drums should be placed on boards or on grids to allow circulation of air to prevent sweating on the bottom.

Hydrofluosilicic acid must be stored either in unopened glass carboys or in rubber-lined shipping containers to prevent the release of gases or vapours. Day tanks should be tightly covered.

TEST FOR FLUORIDES

It is essential for the operating agency to obtain reliable testing equipment to conduct periodic testing of the treated water for fluoride concentrations. A record of the test results is useful for any future questions of liability for damages alleged to result from over or under-feeding of fluorides. Along with analyzing samples collected during certain times of the day, it would be very useful to utilize equipment which would provide a composite sample of the entire day's output of treated water.

Along with the test results, it is essential to compute the fluoride dosage for each day (or longer periods of time). This computation is based on the quantity of fluoride compound used and the amount of water treated. The quantity of fluoride compound used in the computation is obtained from readings of the weigh scale on which the dry feeder or chemical hopper rests, from a recording of the poise position on the beam of gravimetric feeders, from the measurement of the level in fluoride solution tanks, from the meter readings on the line replenishing sodium fluoride saturators (assuming the production of a 4% solution) and from the loss of weight of the hydrofluosilicic acid shipping containers or day tanks. The quantity of water treated is

obtained from reading the master meter, which should be standard equipment in every water plant. It goes without saying that a record of these computations should be kept for reference purposes.

Frequency of Sampling

Samples to be Collected and Analyzed by the Operating Agency:

For the smaller communities (population 5,000 and less), at least one sample should be examined each day. This sample could be collected from either the plant or somewhere in the distribution system. In larger communities (population 5,000 and more) up to a dozen or more distribution samples should be taken each day from a series of perhaps a hundred or more sampling points. The places at which the daily samples are taken should be rotated or changed each day among the total points available. In installations where fluoride is introduced at different locations, it is essential then to collect a sample from each plant along with samples from the distribution system.

From the foregoing, it is evident that it is difficult to specify the exact number of samples required for all plants. The decision on the number of samples required will have to be made by the District Engineer.

Samples to be Collected by the Operating Agency and Submitted to the OWRC Laboratory

During the initial stages of a fluoridation programme, at least one sample per day from each point of application should be collected during the first week of operation, during the next three weeks one sample per week should be submitted and thereafter, the minimum number of samples to be sent to the OWRC laboratory for analysis is two per month.

TABLE I

BASIC INFORMATION ON FLUORIDE CHEMICALS

	SODIUM SILICOFLUORIDE	SODIUM FLUORIDE	HYDROFLUOSILICIC ACID
Form	Powder	Powder	Liquid
Colour	White	White	Clear - Colourless
Chemical Formula	Na_2SiF_6	NaF	H_2SiF_6
Molecular weight of pure compound	188	42	144
Atomic weight of fluoride in pure compound	6 x 19 = 114	19	6 x 19 = 114
% Fluoride in pure compound	$\frac{114}{188} \times 100 = 60.7$	$\frac{19}{42} \times 100 = 45.3$	$\frac{114}{144} \times 100 = 79.2$
% Commercial purity of compound (range)	95 --- 99	95 --- 98	23 --- 30

Actual purity of commercial grade is provided with each shipment of chemical

	SODIUM SILICOFLUORIDE	SODIUM FLUORIDE	HYDROFLUOSILICIC ACID
% Fluoride in commercial grade compound	$95 \times \frac{60.7}{100} = 57.7$; $99 \times \frac{60.7}{100} = 60.1$	$95 \times \frac{45.3}{100} = 43.0$; $98 \times \frac{45.3}{100} = 44.4$	$23 \times \frac{79.2}{100} = 18.2$; $30 \times \frac{79.2}{100} = 23.7$
No. of lbs. of pure fluoride in each 100 lb. of commercial grade	57.7 --- 60.1	43.0 --- 44.4	18.2 --- 23.7
Solubility of compound (Lbs. per 100 lb. at 77^{0}F.)	0.762	4.05	Infinite
pH of saturated solution	3.5	7.6	1.2 (1% sol^N)

SAMPLE CALCULATIONS

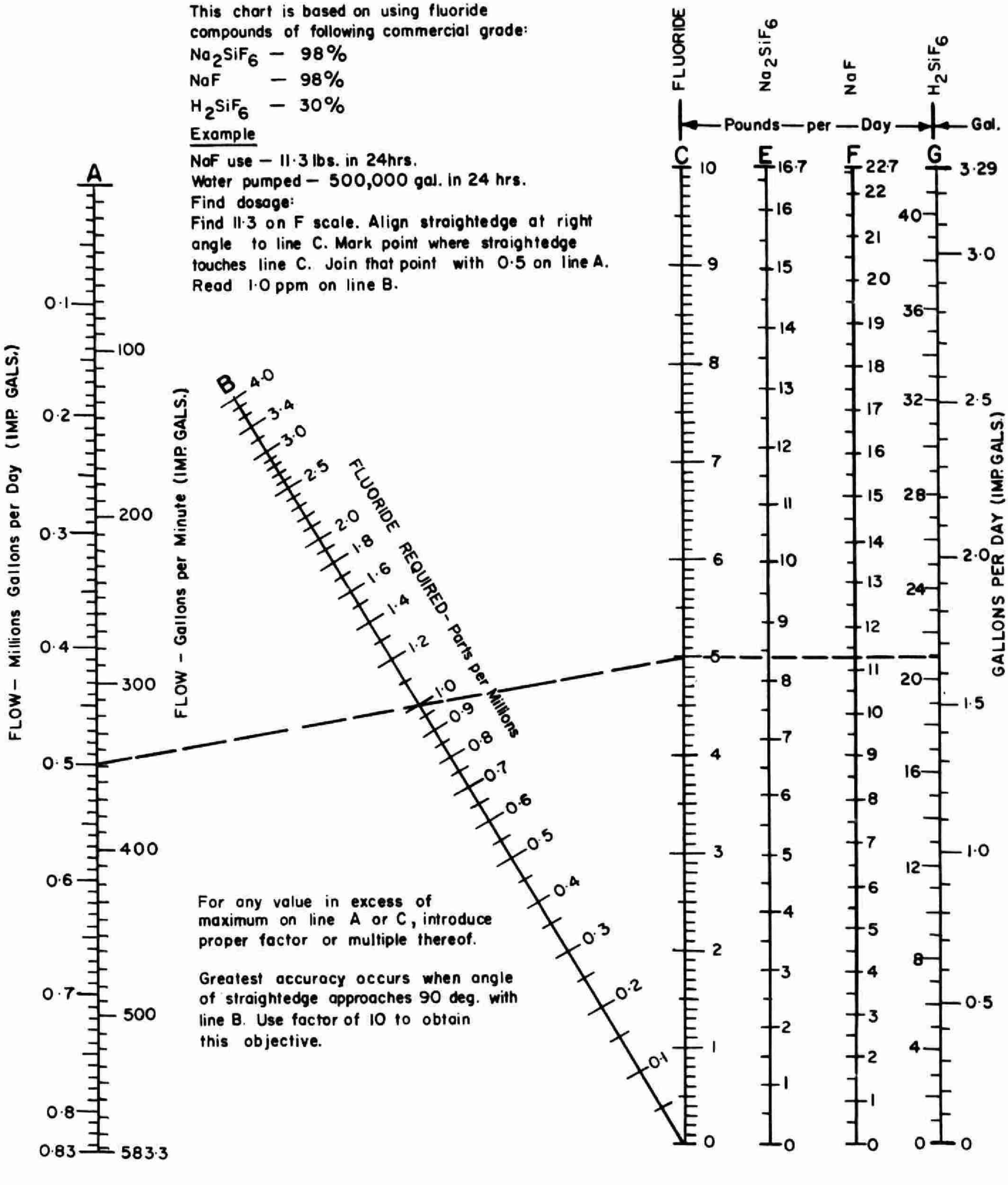
	SODIUM SILICOFLUORIDE	SODIUM FLUORIDE	HYDROFLUOSILICIC ACID
A) To produce 1 ppm - How much chemical (lbs) at above purity per million gall. (Imp.)?	$10 \times \frac{100}{57.7} = 17.3$; $10 \times \frac{100}{60.1} = 16.6$	$10 \times \frac{100}{43.0} = 23.2$; $10 \times \frac{100}{44.4} = 22.5$	$10 \times \frac{100}{18.8} = 53.2$; $10 \times \frac{100}{23.7} = 42.3$
B) To add 0.8 ppm - How much chemical (lbs) per million gall. (Imp.)?	$8 \times \frac{100}{57.7} = 13.8$		
C) To add 0.8 ppm - How much chemical (lbs) to treat 300,000 galls.	$13.8 \times \frac{300,000}{1000,000} = 4.1$		
D) Dosage calculation in 24 hr. period gallons pumped - 500,000			
Pounds of chemical used of commercial grade, as above	8.5 --- 8.3	10.8 --- 10.5	27.0 --- 21.0
Dosage - ppm	$\frac{8.5}{500,000 \times 10} \times \frac{57.7}{100} \times 1000,000$	$\frac{10.8}{500,000 \times 10} \times \frac{43}{100} \times 1000,000$	$\frac{27}{500,000 \times 10} \times \frac{18.2}{100} \times 1000,000$
	= 0.98 --- 1.0	= 0.93 --- 0.93	= 0.98 --- 0.99

TABLE II

CORROSION RESISTANCE OF VARIOUS MATERIALS

EXCELLENT	FAIR	UNSUITABLE	TO BE USED WITH
HASTELLOY C	COPPER	WOOD	H_2SiF_6
STRUCTURAL CARBON	BRASS	MILD STEEL	&
DURIMET 20	MONEL	STAINLESS STEEL	Na_2SiF_6
NEOPRENE	HARD RUBBER	LEAD	
NATURAL RUBBER	WOOD (PITCH-LINED)		
SARAN	GLASS		
TEFLON	CERAMICS		
POLYETHYLENE			
KEL-F			

THE ABOVE INFORMATION WAS TAKEN FROM THE "MANUAL OF WATER FLUORIDATION PRACTICE" BY FRANZ J. MAIER



FLUORIDATION ALIGNMENT CHART

SUSPENDED SOLIDS CONTACT UNITS IN ONTARIO

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INTRODUCTION

The term "suspended solids contact unit" is used to describe a number of manufactured treatment devices which perform coagulation, solids-contact mixing and solids-water separation within a single basin. These units are referred to by such other terms as upflow clarifiers or sludge blanket clarifiers.

The solids are concentrated and removed from the units in the same quantities as they are precipitated.

HISTORY OF DEVELOPMENT

The advantages of returning settled sludge (resulting from chemical reactions in water softening) to raw water being mixed with fresh chemicals became apparent many years ago. It was noted that such practice reduced the amount of finely divided calcium carbonate precipitate; reactions were hastened and made more complete, and effluents were more stable and easily clarified. However, the mechanical return of settled solids was in itself difficult to accomplish and an early development was a "sludge blanket" type of operation in which the liquid undergoing treatment was passed upward through a suspension of previously precipitated solids. Such suspensions are maintained by an upward flow of the liquid undergoing treatment, or by mechanical agitation, or by a combination of the two. In any "sludge blanket" operation the rate at which liquid can be separated from solids in suspension is dependent upon the settling rate of such solids. In some upflow basins the influence of rising velocity to keep solids in suspension was eliminated, and a unique principle was established. That principle embodies the positive recirculation

of slurry (keeping in constant motion heavy uniform suspension of previously precipitated material) independent of the flow rate. The treated liquid is separated from the top of the slurry pool instead of being filtered up through it, and higher clarification rates are made possible.

It was also natural to apply the same principles as described before to the clarification of surface waters where the chemical treatment problem is to reduce colour and turbidity. In this field the advantages of providing contact between raw water and uniform suspension of previously precipitated material in process of recirculation has also been demonstrated. Such advantages include shorter periods for the chemical reactions to take place and higher flow rates by virtue of the larger floc particles formed. The clarity of effluents so produced has been generally better than from the average conventional plant, and the load on filters has been lightened accordingly.

In addition to softening and clarifying municipal supplies, numerous applications have been found in industrial fields where waters of high quality are required for processing and power. A few of the manufactured products involved include pulp and paper, steel, chemicals and petroleum. Many television tube manufacturers and hundreds of bottlers of carbonated beverages also use upflow basins for clarification, alkalinity reduction and the destruction of organic impurities. The latter is accomplished by heavy chlorination during coagulation. In those cases residual chlorine is finally absorbed by granular activated carbon.

The chemical and physical characteristics of waters being treated by accelerated methods vary all the way from supplies having low turbidity, low total dissolved solids, to the hard, highly turbid, or highly coloured surface waters. A case of record in clarification is a Mid-Western river supply used by a municipality in which turbidity changes from 10 to 3000 units occurred within one hour. This water is successfully coagulated with alum only, in an upflow basin, having retention time of one hour, filtration following. This and many other experiences help to confirm the capability of properly designed accelerated treatment units to condition water supplies in basins having retention times of about 1/3 those employed in plants following so-called conventional design.

Nearly all suspended solids contact basins are proprietary. No installation employing a non-patented unit is known to exist in North America.

A partial list of suspended solids contact clarifiers and the respective manufacturers are as follows :-

1. Reactivator - Graver Water Conditioning Company
2. Accelator - Infilco Incorporated
3. Precipitator - The Permutit Company
4. Permujet - The Permutit Company
5. Clariflow - Walker Process Equipment Inc.
6. Hydro-Treator - Dorr-Oliver Incorporated
7. Reactor-Clarifier- The Emico Corporation
8. Pulsator - Degremont Limited
9. Solids Contact Reactor- Cochrane Corporation
10. Contraflo Upflow Clarifier- General Filter Company
11. Accelapak - Infilco Incorporated

SUSPENDED SOLIDS CONTACT UNITS IN ONTARIO WATER TREATMENT PLANTS

In Ontario, these units have been installed at municipal-type water works for softening and iron removal of well waters at Cochrane, for simultaneous softening and clarification at Dresden, for colour reduction at Hawkesbury, and for clarification of other surface supplies having both changing and unchanging raw water qualities. A list of suspended solids contact units at municipal-type water works is given in Table I.

The first unit installed was an Accelator in 1946 for softening and iron removal at Cochrane. A Precipitator was erected at Moose Factory in 1950 to supply the federal installations and townsite. The only Hydro-Treator was installed at Tilbury in 1955. The Union Water System in Essex County, constructed by the OWRC in 1960, is equipped with a Reactivator, an apparently popular unit.

The solids contact units are expected to operate satisfactorily over wide ranges of raw turbidity. Lake water turbidities, ranging from 0 to 200 turbidity units, have been reported at Port Credit. River water turbidities, ranging from 0 to 500 turbidity units have been experienced at Streetsville and Thornbury.

TABLE I

SUSPENDED SOLIDS CONTACT UNITS EMPLOYED IN WATER WORKS IN ONTARIO

YEAR INSTALLED	MUNICIPALITY	UNIT	RATED CAPACITY (U.S. GPM)	SOURCE	CONSTITUENTS REDUCED	OPERATION
1946	Cochrane	Accelator	840	Wells	Hardness & Iron	Continuous
1949	Port Credit	Accelator	1400	Lake Ontario	Turbidity	Intermittent
1950	Moose Twp. Moose Factory	Precipitator	120	Moose River	Iron, Colour & Turbidity.	Continuous
1952	Hawkesbury	Accelator	2800	Ottawa River	Colour (Turbidity)	Continuous
1954	Port Dover	Accelator	700	Lake Erie	Turbidity	Under high turbidity conditions
1955	Tilbury	Hydro-Treator	2000	Lake St. Clair	Turbidity	Continuous
1956	Cayuga	Accelapak	200	Grand River	Turbidity	March to December ±
	Oakville	Accelator	10,060	Lake Ontario	Turbidity	Continuous
1958	Dresden	Accelator	480	Sydenham River	Turbidity & Hardness	Continuous

YEAR INSTALLED	MUNICIPALITY	UNIT	RATED CAPACITY (U.S. GPM)	SOURCE	CONSTITUENTS REDUCED	OPERATION
1958	Lindsay	Accelator	2100	Scugog River	Colour & Turbidity	Continuous
	Streetsville	Accelator	685	Credit River	Turbidity (Colour)	Continuous
	Thornbury	Accelator	540	Beaver River	Turbidity (Colour)	March to December ±
1960	Windsor - Riverside-Tecumseh	Accelator	3000	Detroit River	Turbidity	Continuous
	Union Water System-Essex C.	Reactivator	6600	Lake Erie	Turbidity (Algae)	Continuous
1961	Pickering Twp. J. Sherman Scott	Reactivator	1045	Lake Ontario	Turbidity	Continuous
1961	Crowland Twp. Ford Motor Company Ltd.	Clariflow	1500	Welland River	Turbidity	Continuous
1962	Lakefield	Accelator	216	Otonabee River	Colour & Turbidity	Continuous
1964	Campbellford	Reactor-Clarifier	1040	Trent River	Colour & Turbidity	Continuous

YEAR INSTALLED	MUNICIPALITY	UNIT	RATED CAPACITY (U.S. GPM)	SOURCE	CONSTITUENTS REDUCED	OPERATION
1964	Pittsburgh Township Joyceville Penal Inst.	Reactivator	350	Rideau River	Colour & Turbidity	Continuous
	Port Rowan	Permujet	417	Lake Erie	Colour & Turbidity	Continuous
1965	Tilbury North Township - Stoney Point	-	835	Lake St.Clair	Turbidity	Continuous
1966	Brighton Twp. Warkworth Penal Inst.	Ion Exchange Limited	400	Trent River (Percy Reach)	Colour & Turbidity	Continuous
1966	Lindsay (plant addition)	Reactivator	2100	Scugog River	Colour & Turbidity	Continuous

The units usually reduce the turbidity to less than 10 units, and often less than 5 units. Higher values have been reported at Streetsville and Thornbury while treating raw waters in the 200-500 turbidity units range. It has been the practice for the manufacturer to guarantee an effluent quality of 5 turbidity units.

The highest raw water colour concentration on record with the OWRC was obtained from the Beaver River at Thornbury. It was 125 colour units. High colour concentrations are also experienced at Moose Factory. The raw water colour concentration at Hawkesbury on the Ottawa River is in the 30 to 40 units range.

The effluent colour concentration is almost always less than 5 colour units.

RETENTION AND RISE RATES

The various manufacturers have adopted different designs in offering equipment for sale. However, a retention period of two hours is required in Ontario.

Operators in the U.S.A. have reported good softening and coagulation results with periods of 1 to 2 hours.

Colder waters require longer contact time with the chemicals and slurry. Retention times between 2 and 2.1/2 hours may be required for good coagulation of water supplies in Ontario during the winter months.

It has been found that shorter retention periods can usually be used for softening than for coagulation.

For rated capacities the retention times at plants in Ontario range from 0.8 to 2.5 hours.

The rise rate is usually expressed as GPM/ft^2 of surface area of settling zone. Rise rates not exceeding 1 U.S. GPM/ft^2 have been recommended by plant operators in the U.S.A. when clarifying low turbidity water at low temperature. For colour removal alone the rise rate should not exceed 0.75 U.S. GPM/ft^2. Rise rates between 1.2 and 1.5 are recommended for lime softening.

For rated capacities the rise at plants in Ontario range from 0.71 to 2.7 U.S. GPM/ft^2. Now, the design rise rate for turbidity removal in Ontario is 1.25 U.S. GPM/ft^2.

OPERATION

Solids contact units are used continuously 365 days a year at 14 of the 18 municipal installations in Ontario.

The units at Cayuga and Thornbury on the Grand and Beaver Rivers respectively are not used during the cold winter months.

At Port Credit the Accelator is used only when the raw water turbidity exceeds the 10 to 20 unit range. It was used on 63 days in 1960.

The Accelator is used very intermittently at Port Dover. The unit was used for about six days in 1960.

CHEMICALS AND DOSAGES

Coagulant

Aluminum sulphate (alum) is used at all of the solids contact coagulation installations in Ontario. Alum dosages between 7 ppm (0.5 gpg) and 50 ppm (3.5 gpg) have been recorded at the Ontario plants. (14.1 ppm = 1 gpg).

The coagulant dosage should be as low as possible and still obtain good results. Too much coagulant may make the floc too light for fast settling. As the raw water turbidity or colour increases the amount of coagulant should be increased. If the character of the suspended matter changes, more or less coagulant may be needed.

Coagulant Aids

The floc formed by the coagulant alone may not settle quickly. Where the water is clear and cold and the floc formed is fine and light in density or where colour and organic matter are to be removed, coagulant aids may be added to weigh the floc or aid in neutralizing static charges to form larger floc particles.

Activated silica is used at Lindsay, Hawkesbury and Oakville to weigh the floc. Dosages between 2.2 and 5.5 ppm have been used.

Clay may be added to raw water that is low in natural turbidity. It substitutes for natural suspended matter as well as having some coagulating properties of its own. Clay is available at the Union Water System - Essex County to treat the raw Lake Erie water.

Crushed limestone is used at Streetsville to weigh fine suspended silt particles when the raw water turbidity exceeds 25 ppm. Dosages between 5 and 50 ppm have been recorded.

Other commercial compounds such as Nalcolyte 110, Separan and Hi-pHloc are available for this purpose. Coagulant aids may be used with the purpose of reducing the amount of coagulant required. The best amount of coagulant aid to feed is the least amount that will give good results.

Alkali

For optimum coagulation the pH must be carefully controlled. Changes in the amount of alkalinity and free carbon dioxide in the raw water are seasonal with most surface supplies. If the pH of the water is too low for good coagulation, an alkali is required.

Lime is used at Cayuga for this purpose. Dosages between 20 and 28 ppm have been recorded at this plant.

However, lime is generally used for pH correction for the effluent of the suspended solids contact unit such as at Hawkesbury.

Softening

Where partial softening is required, lime and soda ash are used as reagents.

Lime is used at Dresden to soften the Sydenham River water and at Cochrane to soften well water. The dosages used vary between 85 and 322 ppm (avg. = 155 ppm in 1966) at Dresden and 224 to 400 ppm at Cochrane.

The use of soda ash at Dresden has been discontinued.

Coagulants and coagulant aids may also be used in the lime softening process to remove suspended matter or colour present in surface supplies and to coagulate the fine calcium carbonate precipitates.

Chlorine

An interesting use for chlorine was observed at Hawkesbury. At this installation chlorine is added for the purpose of lowering the pH and thereby reducing the alum dosage. As you are no doubt aware, flocculation occurs at a low pH.

POINT OF CHEMICAL FEED AND ORDER OF CHEMICAL USE

The best point of application varies from plant to plant. This can usually be determined by jar tests.

Some operators find that best performance is obtained when the old sludge contacts incoming water and chemical immediately after entrance into the suspended solids contact unit. If a chemical is added to the water before it reaches the basin it may form new colloidal precipates which do not adhere to the old sludge nuclei.

At one Hydro-treator installation in the U.S.A., the addition of lime for softening directly into the basin caused the sludge to cement and stop the distributor arms. This was eliminated by adding the lime to the raw water line ahead of the unit.

Experience has shown that the order of adding coagulants and coagulant aids can make a significant difference in the results achieved. This should be determined at each plant by experiment and/or by jar tests.

NORMAL OPERATION

Each equipment supplier has his own set of operating instructions. The details vary because of the differences in equipment and design principles used.

It is hoped that the following general procedures may be applied to all municipal installations in Ontario.

INITIAL OPERATION

All water lines should be flushed out to remove mud and scale. Any grease or oil should be removed from the interior faces of the equipment. The drain line and sludge removal system should also be flushed clear.

After optimum chemical dosages have been determined from the raw water analyses, the chemical feed systems should be charged and placed in operation while the unit is filling.

The unit should be filled using a rate of approximately 1/2 to 2/3 of rated capacity. When the water reaches the effluent launders they should be checked for level.

The use of a low agitator speed is recommended during the start-up period at coagulation plants. Higher speeds may be necessary at softening plants.

During the initial start-up period the effluent should be discharged to waste. This is to prevent carry-over of excessive turbidity to the filters or to the distribution system, until such a time that satisfactory treatment has been established.

Continuous water flow at the above rates and adjusted chemical feed rates should be maintained until the desired sludge concentration is reached. Once a slurry is formed normal rates and chemical dosages may be used.

De-sludging should not be started until a full sludge blanket has been formed. It may take several days to build up a satisfactory blanket depending on the water characteristics. The time required may be shortened by feeding large amounts of chemicals or clay but best results will not be obtained until the types of solids and their density reach an equilibrium value with proper amounts of chemicals fed.

During the start-up period, the sludge withdrawal line should be back-flushed a minimum of once or twice a day for up to 20 seconds to maintain it free of solids. The rate of back-flush should be such that the sludge is not raised to the surface.

AGITATOR SPEED

During the normal operation, the agitator should be run as fast as possible without causing disturbance of the sludge blanket. Agitation must be great enough to thoroughly mix the slurry, raw water and chemicals and to keep them is suspension.

Some operators feel that proper agitation to obtain maximum contact with the old sludge particles is more important than the concentration of the solids.

With low turbidity waters the best operation is often obtained with the agitator speed reduced. Generally, when treating cold water the agitator speed should be increased.

SLURRY STRENGTH

The actual strength of slurry to be carried will vary with load, temperature, characteristics of the precipitate and other factors. After sampling over a period of good operation, the operator should learn the proper slurry strength for his particular plant.

The concentration of solids is measured by a volume settling test. A 100 ml sample of the slurry is collected in a 100 ml graduated cylinder and allowed to settle. The settling time used varies among the manufacturers from 5 to 20 minutes. The volume occupied at the end of the settling period is the strength in percent solids.

Slurry strength may be determined at more than one point in the tank. At Reactivator plants sludge is sampled at the lower and upper draft tubes and allowed to settle for 10 minutes. The manufacturer recommends that the two concentrations should not differ from each other by more than 5%. At the Union Water System Essex County, a concentration of 20% ± is carried.

It is therefore difficult to compare slurry concentrations from plant to plant unless they are of the same type. At the Accelator plants in Ontario slurry strengths from 5% to 20% based on a 5 minute settling test are carried.

Although a slurry is necessary for coagulation, its exact concentration within allowable limits is not too critical.

Softening seems to improve as the slurry concentration increases. Therefore the highest concentration that will not result in floc carry over should be used.

SLUDGE REMOVAL

The weight of solids discharged from the sludge hoppers or concentrators must equal the weight of solids formed.

The amount of waste water is very similar to that of other types of treatment. The amount wasted ranges from 1 to 5% of the total treated water for coagulation units and from 0.5 to 4% for softening units. The amount of blow-down may also be expressed as from 0.2 to 1.0% of inlet water for each 100 units removed.

The concentration of solids in the blow-off of the sludge concentrator is usually from 80 to 95%.

The volume of sludge to be wasted can be calculated from the weight of chemicals added, total weight of impurities removed from the raw water, and the density of the sludge. Once this is known the automatic blow-off valves can be set to discharge at frequent intervals during the day.

For those units equipped with back-flushing devices each back-flush may last from 5 to 20 seconds but will vary with local conditions. The sludge should be examined during blow-off. If there is dense sludge followed by very thin sludge, the back-flush time should be lengthened. If the sludge is thin for the entire time the back-flush is too long.

BOTTOM DRAIN

The bottom drain connection is used to remove accumulations of heavy sludge or sand which are too heavy to be kept in circulation.

The drain should be opened regularly as found necessary (perhaps weekly) by experience. The agitator should be run when the drain is open. The valve should be opened full and held open until heavy sludge or large particles no longer appear. An excessive amount should not be discharged as this decreases the solids in circulation.

It is considered good practice to drain and clean these units once every six months. Especially should this be done at softening plants. Lime or lime-soda ash softening reactions may create a scaling condition. The scale can build up on the mechanical moving parts and the steel partitions. This added weight may damage the drive mechanisms and/or supporting structures unless the scale is removed regularly.

ADJUSTING CHEMICAL DOSAGES

Too high a coagulant dosage decreases the density of the sludge. This may cause the sludge blanket to rise beyond the maximum desirable limit, possibly causing a carry-over of sludge.

Since the action of the coagulant is affected by the pH value of water, it is necessary to control the pH within a certain range. Colour is most effectively removed at low pH. Where turbidity removal alone is desired, the pH range can be wider.

If the slurry concentration decreases and the level rises it is usually due to incorrect chemical treatment or faulty coagulation. A temporary decrease in mixing speed may be necessary until proper dosages are determined. If the chemical tests indicate that treatment should be changed, the base charges or feed rates should be increased or decreased from 2 to 5% at a time.

OPERATING DIFFICULTIES

Rate of Flow

All sudden increases in rate of flow should be avoided. Increases in rate of flow should be accomplished slowly to prevent upsetting the sludge blanket.

The units should not be operated at too low a rate. Sizeable surges at half design flow are more of a problem than at design flow. The slurry is usually thinner at lower rates and more difficult to keep in suspension.

In operating at a varying rate of flow, it is desirable to carry the sludge blanket at a lower level in order to ensure a greater margin of safety. If the rate of flow is constant, the sludge level may be carried higher.

Some operators in the U.S.A. have reported that as long as the chemical feed and waste sludge controls are changed accordingly, the changes in rate of flow from 50 to 130% of rated capacity do not upset the units. However, in this study no attempt was made to compare the rise rates at these plants with those where such changes caused upsets.

Changes in Raw Water Quality

Sudden changes in the physical and chemical qualities of the raw water can be disturbing unless detected soon afterwards.

Under such conditions chemical control tests should be conducted every hour or two hours. It may, however, take from 3 to 4 hours for the changed chemical dosages to establish equilibrium.

Gases in the Raw Water

In softening plants treating well supplies, sufficient aeration should be provided ahead of the suspended solids contact unit to drive off dissolved gases in the raw water. Otherwise the gases will tend to raise and float the slurry.

When present in surface supplies, algae should be controlled by the use of micro strainers and/or pre-chlorination to prevent growth in the solids contact unit, with the release of carbon dioxide gas during the respiration cycle.

Suspended air may be introduced in pump suction piping and pump glands in both the raw water supply and chemical feed systems.

Organic Solids In The Slurry

A sludge blanket loaded with decomposing organic material such as algae is a breeding place for taste and odour. The blanket may deteriorate causing heavy carry-over into the effluent. In such cases sufficient pre-chlorination may be required to give a free chlorine residual.

If heavy chlorination still results in a pronounced taste and odour, it becomes necessary to provide activated carbon treatment. For example, activated carbon is fed directly into the Accelator at Streetsville during periods of the year when the Credit River is susceptable to taste and odour conditions.

Temperature Changes And Sunlight

Temperature changes of the raw water source are usually not abrupt enough to disturb the slurry in the solids contact units. Temperature changes in excess of $2^{o}F$ per hour may cause difficulty.

Local temperature changes due to the sun shining on open tanks do cause variation of the slurry level. One operator in the U.S.A. reported that the level appears to drop at night and on cloudy days and to rise again when sunlight returns. Similar observations have been made at the Union Water System-Essex County treatment plant.

Chemical Feed Interruptions

For best results there should be no interruptions in chemical feeding. Some operators in the U.S.A. reported no serious effect upon water quality for short interruptions up to 30 minutes while others reported a noticeable carry-over of alum floc within 10 minutes. Clay and lime feed interruptions did not seem to have such a marked effect.

At softening plants the hardness increased, the size of particles in the slurry decreased, and the effluent turbidity increased when lime and alum dosages were too low. Variations in soda ash feed appeared to have less adverse effect.

OPERATING INSTRUCTIONS

Maintaining The Slurry Level

The top of the slurry blanket is kept at the best operating level by varying the sludge blowoff. Assuming that the slurry strength remains constant, if the blanket level goes up, the blowoff should be increased, and if the level drops, the blowoff should be reduced.

One of the factors listed in the table below may raise or lower the blanket level. It is not desirable to change the blowoff rate if the condition is only temporary. By sampling the slurry strength and using the table as a guide, the operator can determine when to change the blowoff rate and when to leave it alone.

TABLE II

Factors Increasing Slurry Strength or Lowering Blanket Level	Factors Decreasing Slurry Strength or Raising Blanket Level
Lower Rate	Higher Rate

(table)

Higher hardness of Inlet Water (lime softening)	Lower Hardness of Inlet Water (lime softening)
Higher Inlet Water Turbidity. Heavier Inlet Water Turbidity	Lower Inlet Water Turbidity. Finer or Lighter Inlet Water Turbidity.
Higher Inlet Water Temperature	Lower Inlet Water Temperature
Use of Coagulant Aids	Increased amount of coagulant

CHECK LIST OF OPERATING DIFFICULTIES

Symptoms	Causes	Check Points
1. High turbidity Cloudy appearance	1. Inadequate chemical treatment	a. check treated water analysis b. check chemical feeders c. check chemical treat-ment requirements by jar tests.
	2. Insufficient sludge in circulation	a. check agitator speed b. check sludge cone c. check blowoff devices for proper operation.
II. Continuous Floc carry-over with low sludge level in settling zone.	1. Inadequate chemical treatment.	a. check treated water analysis. b. check chemical feeders c. check chemical treat-ment requirements by jar tests.
	2. Excessive agitator speed.	a. check agitator speed.

Symptoms	Causes	Check Points
	3. Air entrainment	a. check raw water piping for air introduction. b. check raw water pumps for air leakage through glands. c. check chemical pumps for air leakage through glands. d. check chemical feed system for air introduced by vortexing.
III. Intermittent or periodic floc carry-over with low sludge level in settling zone.	1. Variable raw water composition.	a. check raw water analysis during difficult period. b. check treated water analysis during difficult period. c. run jar tests to determine treatment requirements during difficult period.
	2. Erratic feeder operation.	a. check chemical feed controls. b. check chemical feeders for bridging. c. check chemical feeder calibration. d. check chemical pump delivery.
	3. Variable raw water temperature	a. continuously check raw water temperature. b. run jar tests to find treatment to give heavier floc.

Symptoms	Causes	Check Points
	4. Air entrainment	a. check raw water piping for air introduction. b. check raw water pumps for air leakage through glands. c. check chemical pumps for air leakage through glands. d. check chemical feed system for air introduction by vortexing.
	5. Repeated flow surging.	a. check inlet control device for proper operation. b. check level controller for proper operation. c. check raw water pressure for variations.
	6. Variable sludge concentration.	a. check sludge concentration. b. check blow-off device for proper operation.
	7. Excessive back-flush	a. check back-flush water pressure. b. check back-flush timer setting.

IV. High sludge level in settling zone.	1. Excessive quantities of sludge in unit.	a. check blow-off device. b. check sludge concentration c. check agitator speed. d. where applicable, check scraper operation.
	2. Light Sludge	a. check blowoff sludge conc. b. check treated water analysis. c. check raw water analysis. d. check chemical feeder operation. e. check for settling rate in jar tests. f. check for septic sludge-odour, colour, pH. g. check agitator speed.

RAPID SAND FILTERS
OPERATION AND MAINTENANCE

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Hamilton Water Purification Plant

GENERAL CONSIDERATIONS

The major portion of the potable and industrial water supply in Ontario is derived from surface waters-lakes, rivers and streams. Since most of us are aware of what is happening to these surface waters today in the way of pollution, the need for adequate treatment to render them safe for consumption is self-evident. The water purification plant man is aware of the fact that he must not only assure the public a safe water but provide as well a product which has no objectionable taste, odour or colour.

These end results of the treatment process may be achieved by applying numerous methods of treatment to the "raw" water entering the plant. It can be treated with various chemicals, agitated by mechanical means to ensure proper mixing and coagulation of the chemicals so as to ensure adequate flocculation, and allowed time enough during its flow through the plant for most of the suspended matter contained in it to settle out. The last, and most important phase through which it passes is - FILTRATION.

Filtration is a comprehensive subject in itself and much has been written on the topic. No attempt will be made in these notes to discuss the purely theoretical aspects of the mechanics of filtration since the writer is not suitably qualified to expound on the subject, which requires some familiarity with higher mathematics and physics. However, there are many papers and treatises which have been written on this and they may be found in such publications as the AWWA Journals, and numerous other water works manuals. It should be mentioned here that the OWRC laboratory has a very fine and extensive library, from which reference material may be obtained on this and allied subject matter.

In discussing filtration, it would perhaps be as well at the outset to arrive at an acceptable definition of the word. To put it simply, Filtration is the process of separating turbidity, or suspended particulate matter, from water by passing it through some porous filter media such as sand, anthrafilt or a combination of both.

There are a number of methods in use today which with varying degrees of success accomplish the aforementioned results. There are slow sand filters, rapid sand filters, Diatomite filters, Microstrainer units and more recently a filter construction known under the trade name of "Micro Floc". Anyone of these methods may be combined with any other to achieve optimum results. For instance microstrainers may be used ahead of coagulation, sedimentation, and filtration where the incidence of algae concentrations is high or seasonal. However, the majority of water purification plants in Ontario of appreciable size use the free surface rapid sand or sand/anthrafilt filters and these latter units are utilized in our Hamilton plant.

Water Purification Plant Operators are practical men, and for practical purposes filtration should properly be considered as the final mechanical treatment which the water undergoes in the plant processing; the "Polishing Off" Operation, during which any residual turbidity carried over from previous stages of treatment is removed. Filtration removes some bacteria from water and possibly some viruses, since it can logically be assumed that many of these organisms will be bound up in the floc particles and particulate matter.

In the opening paragraph of these notes, mention was made of pollution. This problem, as you well know, is assuming increasing magnitude. As pollution of raw water supplies worsens, so then in direct proportion does it evolve upon the plant operator to keep a sharply critical eye on the treatment methods employed so as to ensure the highest possible quality of "Finished Water."

In some local areas genuine efforts are being made to reduce or eliminate pollution of supplies, but considering the whole picture, especially the Great Lakes System, the situation seems to be deteriorating. Much effort, time, and money is being put forth by the various levels of government through agencies such as the OWRC to combat this growing threat to man's health and well being.

One result of the awareness of the problem is evident in the proposals recommended by the Purification Division of the AWWA - in the matter of quality goals for potable water. The quality criteria advocated are more exacting than those previously put forth, but still not impractical of attainment. Among the most important of these objectives from our point of view are these:

Turbidity - less than 0.1 ppm

Colour - less than 3 units

Odour - no odour

Taste - no objectionable taste

Nuisance Organisms - no Coliform Organisms

Hardness - 80 mg/l (as $Ca\ CO_3$)

The attainment of such objectives imposes exacting demands on the Plant Operator. For instance the decision as to which chemicals to use for pretreatment will have to be considered not only in regard to optimum efficiency for flocculation and coagulation; it will have to be related to flow-through time as well. The demand on water treatment plants is increasing annually. If a given chemical treatment will produce a good floc, coagulate well, and result in a water over the filters of say 1.0 ppm at a flow rate of 25 MGD an increase in flow rate to 40 MGD will obviously not produce the same quality water over the filters even with a proportionately increased chemical dosage, since, with the flow rate increased by 60% less time will have elapsed for the floc to settle out, resulting in a greater carry over to the filters. The net consequence will be shorter filter runs. This is but one problem to be considered. It also points up another responsibility of the plant operator, namely, to keep his superiors well informed on all aspects of plant performance, noting especially the rate at which demand is increasing, effectiveness of pretreatment etc., so that the Engineering Department will be able to plan ahead for needed expansion of facilities before such a need has actually arrived.

SLOW SAND FILTERS VS. RAPID SAND TYPE

By a slow sand filter is generally meant one in which the water flows downward through the bed at low velocity, i.e. 0.032 to 0.160 gpm per ft. sq. A rapid sand filter is one

which has a flow-through of 2.0 gpm per ft. sq. or higher (usually from 2.0 to 4.0 gpm per ft. sq.). But recent research has shown that considerably higher rates than these may be achieved. It must be emphasized that great care has to be taken in the raw water conditioning treatment applied where such high rates are used. As a rule of thumb the higher the filtration rates utilized, the better must be the quality of the water over the filters, necessitating more adequate and effective treatment methods adopted in the raw water conditioning. We have a total of 24 filter units in the Hamilton plant, each filter having a surface area of 1440 sq. ft. The filters are of conventional construction, each being essentially a concrete box on the floor of which are laid parallel rows of 4" C.I. pipe on 12" centers having 9/16" brass bushed holes on the underside on 6" centers. This comprises the underdrain system. Overlying the underdrains are the layers of gravel of various sizes, from 2½" on the bottom to the "pea" gravel on top, over which is placed the filter media, 13" of sand capped with 15" of anthrafilt. The sand effective size is 0.5 mm and the anthrafilt effective size is 0.70 mm. Approximately 3" above the top of the anthrafilt are positioned the Palmer sweep arms of the surface wash equipment. The supporting members of these are fixed by means of through bolts and brackets to the underside of the wash troughs. There are six rotating arms in each filter, three in each half section. The wash troughs are positioned over the filter bed, the lip of the troughs being 42" above the top of the anthrafilt. The wash troughs in each filter half drain into a common gully from which the wash water is drained to waste. The filters are operated at a maximum rate of 5 mgd each being equivalent to a rate of 2.43 gpm per ft. sq. through the filter media.

OPERATION

There is considerable literature available on the operation of sand filters and while these notes may in some instances be considered generally applicable to all sand filters they are more particularly centred around the operation of those in our Hamilton Plant.

The most important point to remember concerning the water which arrives at your filters is that it must be adequately and thoroughly conditioned and pretreated before it ever gets there. Without this pretreatment process, (or carrying it out inadequately) many undesirable conditions are likely to occur. The operating efficiency of your filters is going to be drastically reduced. Filter runs will be cut short, resulting in a considerable increase in the amount of wash water used, with a consequent reduction in plant output since filters have to be washed with filtered water. The filter beds will become overloaded

with algae and particulate matter, and mud balls are very likely to develop, and this last mentioned condition can be very annoying and troublesome indeed.

The nature of the conditioning which you apply to your raw water will depend of course on the quality of the water entering your plant. We are rather fortunate in Hamilton in this regard for while we may have to meet a pollution problem of a minor nature at times, our raw water turbidities are generally well below 5.0 ppm. Our raw water enters a low lift pumping station on the shore of Lake Ontario from two intakes, one of 48" diameter and the other of 60" diameter which extend out into the lake 2,100 ft. and 3,000 ft. respectively. The water is pumped a distance of approximately 1,500 ft. to our treatment plant, where it enters the chemical mixing building. Our present pretreatment consists of pre-chlorination and the use of aluminum sulphate as a coagulant. The pre-chlorine dosage is such as to maintain a chlorine residual (total combined) at the point of application of 1.0 ppm when the ammonias in the raw water do not exceed 0.10 ppm. The pre-chlorine dose is increased to maintain a total combined chlorine residual of 1.5 ppm when the ammonias exceed 0.10 ppm. Generally the ammonias are in the order of 0.01 to 0.03 ppm. It should be mentioned here that keeping a constant check (hourly) on the amount of ammonia in the raw water as it enters the plant gives you better control over the chlorination procedures and also allows considerable savings in the volume of chlorine used, especially if you are utilizing automatic chlorination. As mentioned previously, the turbidity of our raw water is generally below 5.0 ppm and we do not initiate alum treatment until this point is reached. Many plants use alum continuously. A problem we have to contend with and one which is common to many Canadian treatment plants, is that of low water temperatures during fall and winter months. The water temperature at times is just slightly over the freezing point, which of course makes coagulation and flocculation very difficult.

A sampling of turbidities was taken one day recently as these notes were being prepared. The results were as follows:

Raw Water turbidity 2.6 ppm. Turbidity of water over filters - 0.88 ppm, and clear well turbidity 0.30 ppm. - No alum treatment used.

FILTER RUNS

The factors which effect our filter runs are pretty much the same as those prevailing at other plants around Lake Ontario - algae concentration and types, turbidity carry-over

from settling basins, formation of mud balls in the filter media, condition of filter beds etc. However, with surface wash equipment installed most of these problems are minimized in great measure and one in particular - the formation of mud balls in filter media, is practically non-existent. We allow filters to run a maximum 48 to 72 hours or until the loss of head through the filter reaches a value of 8.0 ft. before washing. Some operators follow a different procedure. One such told us that his filters were washed every 24 hours of run time but this was in part attributed to the fact that 75% of his filters were not equipped with loss of head gauges. This is fine if you have lots of water to waste, but in the end a rather expensive and needless procedure. Reliable gauges and instruments (if properly maintained and kept in calibration) will indicate your filter status at all times and even give warning of impending trouble, such as break-throughs.

FILTER WASHING

Filters get dirty and have to be washed. Back washing manually follows a fairly well standardized procedure in any plant. The filter influent valve is closed, water is allowed to drain through the bed to top of wash trough, effluent valve is closed, waste valve is opened and wash valve is opened to begin washing. One of the greatest boons to efficient filter operation has been the introduction of "Surface Washers" or "Filter Bed Agitators". These consist essentially of tubular rotating arms having small jets positioned along their length, the whole assembly being held in place about three inches above the top of the filter media. The "agitator" arms rotate on special thrust bearings having packing to keep filter media from entering. Water under fairly high pressure (80 psi in our plant) is piped through 4" headers to the rotating arms.

Operation of the agitator arms is initiated a minute or so prior to the start of the back wash in order to more effectively break up the entrapped particulate matter (GUNK) in the top few inches of the filter media. The wash valve is opened sufficiently to give a wash rate of 12" rise per minute through the bed, (9000 gpm) for two minutes and then increased to a value of 25" rise per minute (19000 gpm), which expands the filter media approximately 50%. It is during this phase of the wash that the effectiveness of the surface wash equipment is made evident. Water, thrust from the jet nozzles (1/8" to 3/16" diameter) at high velocity as the arms rotate creates a condition of great turbulence wherein the expanded filter media is subjected to the full force of the jet blasts, and is

thoroughly scoured and cleaned in the process. This high rate wash is maintained for approximately five minutes and the agitator arms are stopped about a minute before the wash valve is closed. A full wash uses up approximately 120,000 gallons of water. Wash water consumption in our plant runs in the range of 0.6% to 1.5% of filter plant output. Some plants employ a system of wash water pumps discharging directly into the wash water trunk line during the backwash cycle. Our wash water flows by gravity from an elevated storage tank of some 260,000 gallons capacity. The tank is 16 feet in depth and forms an integral part of the filter building structure. The bottom of the wash water storage tank is at an elevation of 40 feet above the centre line of the wash water line in the filter pipe gallery. Water is delivered to the tank by four pumps rated at 2,000 gpm each which may be operated either singly or in multiple. Ordinarily two pumps are in service at one time, the controls for the pump drive motors being actuated through float switches. The filter back wash rate in terms of flow through the bed is 5 to 6 times greater than that existing during filtration.

It is important that the correct wash rates be used during filter washing. Too low a rate will not expand the media sufficiently for efficient washing nor float the entrapped turbidity to the surface. Too high a rate can result in damage to the bed, resulting in loss of anthrafilt and "mounding" of the small sized gravels especially the "pea" gravel layer which supports the sand bed. After a filter is washed, it is considered good practice to leave it for at least one hour before returning to service. This allows the media to "set" or become consolidated, prior to the next filter cycle. High rates 30" and over if bed is fluid and rate increased slowly.

FILTER MAINTENANCE AND INSTRUMENTATION

There are many and varied types of appurtenances to be maintained in connection with filters. These include hydraulically or pneumatically operated gate valves, butterfly valves, sluice gates, rate of flow controllers, surface wash equipment, and the instruments associated with the filter operation such as loss of head and rate of flow gauges, as well as the gauges used for indicating and recording the wash rates. The importance of a good maintenance program cannot be too strongly emphasized. To be effective and efficient the maintenance program must be based on a policy which is directed towards anticipating troubles likely to occur with any given piece of equipment, as well as keeping abreast of

routine maintenance. In this regard the matter of keeping proper records should be mentioned. If you have a full and complete record of past troubles and breakdowns, including the repairs necessitated, a periodic review of such records will alert you to possible future trouble spots. Also, any downtime resulting from a breakdown of equipment can be minimized by keeping on hand sufficient spare parts and having adequate facilities and tools to accomplish repairs. There are limitations here of course. You cannot possibly foresee every eventuality, but from past records and experiences the odds are on your side if you keep "on top of" your maintenance procedure.

As to actual maintenance required, we have found that the operating cylinders on the various valves; influent, effluent, wash and waste, need periodic checking to replace gland packing and the occasional replacement of new cup leathers on the piston. When we remove a cylinder from a valve for this latter job, we bolt a blank wooden flange faced with rubber gasket on one end of the cylinder, and fill the cylinder with a fairly strong solution of muriatic acid and hot water. This effectively cleans the plating of calcium bicarbonate from the brass liner of the cylinder and leaves the bore smooth. If, after some years of operation you find that one end of the cylinder liner is scored, you can invert the cylinder when replacing it. Usually you will find more scoring on the bottom of the cylinder liner.

When replacing rounds of packing in the cylinder packing or stuffing boxes use the proper grade of packing for the particular service, grease each round of packing liberally with a pump grease, be sure to "stagger" the split ends of the packing radially on the valve stem and lastly make sure that the glands are pulled down evenly but not too tightly. A "cocked" gland can exert a tremendous friction load on the valve stem.

The surface wash equipment does not require too much maintenance other than an occasional cleaning of the jets on the agitator arms. Some fine grains of anthrafilt become lodged in the jets it is a simple matter to unscrew these for cleaning. Even though this is a minor maintenance chore it should be done periodically, because the agitator arms will not perform effectively if a number of jets become clogged. The ball bearings on which the agitator arms rotate do not give much trouble. We have changed only one in six years of operation and that one was defective as originally installed.

If you have surface wash agitator arms and the water headers which supply them are of steel or wrought iron, keep an eye on the condition of the piping. Our first installation was of wrought iron piping for these headers and within three years they had to be replaced because of surface corrosion which was eating through the pipe walls. We replaced these with P.V.C. pipe and fittings, and will never again be bothered with such a problem as corrosion in that installation. P.V.C. piping has many advantages over steel or iron, but care has to be taken in bracing and supporting the installation, as it does not have the rigidity of steel.

The maintenance of the filter bed itself in our plant involves a periodic "probe" check of the sand/anthrafilt to determine the contours of the pea gravel layer. This should be done twice per year. We make up an outline sketch of the filter area and enter on this at the appropriate point the reading obtained by the "probe". To explain; the water in the filter to be checked is drained through the anthrafilt. A man, walking along the wash troughs thrusts a six foot length of steel rod down through the filter media until he feels the bottom of the rod come into contact with the pea gravel. Checking a marker near the top of the rod against the lip of the wash trough he determines the depth of the gravel at that point. Since the top of our filter troughs are approximately 42" above the top of the anthrafilt in the bed, the depth to pea gravel should be 42" + 15" (anthrafilt) + 13" (sand) or a total of 70" from lip of trough to top of pea gravel. Checks are made in this manner over the whole bed and an accurate picture obtained of the gravel contours. If undue "humping" of gravel is found, the sand and anthrafilt are removed from the area and the pea gravel re-graded.

INSTRUMENT CHECKING AND MAINTENANCE

The usual gauges on filter consoles are those which indicate two functions-loss of head and rate of flow. These instruments will indicate correctly only if they are given periodic calibration checks and maintenance. No matter how sophisticated the instrumentation is, there are two very simple checks which will prove out their accuracy.

To check the actual loss of head through any filter, obtain a length of polyethylene tubing, ¼" or 3/8" diameter, pass one end down to the pipe gallery floor from the filter console above, connect the tubing to a centre tap on the filter effluent line and open the tap allowing water to rise in tubing. The distance from the level of the water in your filter to the level of water in the tube in inches or feet is the actual loss of head across your filter at the moment. If the indication on the gauge on your filter console is not in agreement with this value, plus or minus the allowable tolerance your gauge is wrong, whether it costs $50.00 or $1000.00. What you are doing here is taking a true piezometer reading of the hydraulic gradient across your filter.

To check your actual rate of flow through the filter, a "Hook Gauge" is very accurate. This consists essentially of a supporting member (1/8" x 1" strap iron or similar) about 48" long to which are fastened two small brackets. On each bracket is positioned a ¼" x 1½" brass machine screw which has been ground to a needle point at one end. The pointed ends of the brass screws are held in the vertial position by means of the small brackets and lock nuts. You can position these two "points" on the hook gauge so that the distance between points is exactly six inches or 1 foot, whichever dimension you prefer. (A stop watch is used with the hook gauge.) In use, the top end of the strap iron is bent at right angles and the gauge is lowered into the filter, between any two wash troughs. To check the actual filter rate, close the filter influent valve leaving the effluent valve open. Watch the water dropping in the filter and when the water just "breaks" the top point on your gauge, start your stop watch going. Stop the watch exactly at the point where the dropping water just "breaks" the bottom "point" of your gauge. What you are doing of course is measuring accurately the time taken for the filter to pass either 6" or one foot of water in a given time. Knowing your filter area, you can calculate the rate in terms of MGD, which your console instrument shows. Again you are obtaining a very accurate check on a filter function, because here you are measuring a given volume of water passing through the filter in a given time. Allowances must be made in these calculations for the space occupied within the filter by such appurtenances as wash water troughs and gully walls, and whether the time is checked with the water level above the troughs or below them.

TURBIDITY

There are many makes of turbidity measuring devices on the market, and probably as many claims made for their accuracy as there are models offered for sale. But as one writer in an AWWA Journal said a few years ago, "It is a well recognized fact that turbidity is a very indefinite quality to measure. Many problems prevent the accurate determination of an absolute turbidity level for any water sample." However, there are some very good instruments available tody which are much more accurate than any previous makes or models, and they do a very good job in the plant. Having instruments such as these is really a "must" for the plant operator who must constantly know the status of his filters. For instance, the shift operator can see at a glance the condition of the raw water (turbidity) and is able to determine at what point he will have to initiate chemical treatment for coagulation. With another turbidity instrument continuously monitoring your plant effluent, any sudden or unexpected breakthrough of turbidity in the filters will be made known immediately, and remedial action can be taken. There are also portable Laboratory type of instruments which are quite accurate over a wide range and with these a check can be made at any time on the turbidity of any individual filter by taking a sample from the filter (effluent) to be checked.

A good policy to follow in regard to instrumentation is this: do not go about day by day blithely accepting the evidence shown on your indicating gauges or recorders as being absolutely correct. Do some periodic checks and calibration tests to prove them out.

HANDLING FILTER MEDIA

Should it become necessary to remove the filter media from any filter for any reason, you will want to have equipment which is capable of moving the sand or anthrafilt quickly and with the least amount of labour expended. There is no easy way around this problem (shovels, and muscles are still required), but there is one piece of equipment which greatly facilitates the job. This is an EDUCTOR. It is portable and can be moved around and put in place with little effort. It is fabricated of steel, and is simply a cone shaped hopper fitted at the base with pipe fittings and adaptors for rubber hose at inlet and discharge side. Within the pipes at the bottom of the hopper are placed a nozzle and throat piece usually made of manganese steel for long wear.

Nozzle and throat piece are positioned about one inch apart on a common axis, the nozzle being smaller in diameter than the throat piece. Water at comparatively high pressure (60-80 psi) is fed into the inlet side and exits at high velocity through the nozzle, (inlet pipe size 2½", nozzle size-1" pipe) directly into the throat piece. The filter media is shovelled into the hopper and is drawn into the space between nozzle and throat and ejected through the discharge piping and hose. The hopper can be placed within the filter, water supply line and discharge hoses connected up and the filter media moved wherever you wish. We have used this device a number of times with much success. It is certainly a great time and labour saving piece of equipment. In addition to its efficiency in moving filter media it is also very effective in cleaning and scouring the sand or anthrafilt grains as they move at high velocity through the throat and out the discharge hose.

MISCELLANEOUS NOTES ON FILTER TROUBLES

Every filtration plant has its own particular problems to contend with, some of these being common to other plants and some peculiar to that one plant alone. Some enquiries were made at other plants while preparing these notes in an effort to ascertain their particular problems.

"Air Binding" or "Air Locking" is a condition met with in some plants, especially in water of very low temperature. This was rather a severe problem at the Brantford plant some years ago when their filter media consisted of sand only.

Mr. Don William of that plant states that air bubbles "as large as pumpkins" developed and he ascribed the condition to a high content of dissolved nitrogen. With the introduction of anthrafilt to the filter media the severity of this condition decreased noticeably, the air bubbles released were quite small and were distributed evenly over the filter bed. Another problem experienced at the same plant had to do with the anthrafilt becoming coated with a substance which Mr. Williams analyzed and found to be pure Lanolin. Subsequent investigation pinpointed the source of the pollution as a wool processing plant located upstream from the Brantford plant. The remedial measures employed in removing the sludge thus formed in the top portion of the anthrafilt by the Lanolin consisted of prolonged backwashing of filters (10-15 minutes).

Activated carbon is used at the Brantford plant and Mr. Williams notes that any carbon breakthrough in the filters is due in large measure to poor backwashing and also to varying the filter rate while in operation (increasing or decreasing).

The plant at Welland draws its water from the Welland canal and oil from shipping adhering to filter walls necessitates frequent scrubbing.

If it is suspected or proved that sand is being lost from a filter the only recourse is to remove the wash water elbow or wash-effluent tee in order to gain access to the filter effluent manifold in order to remove the sand, which will usually be found deposited in the area of the manifold furthest from the effluent wall thimble. It is good practice while in the filter effluent manifold to check for cracks or ruptures in the cast iron plate assemblies of the underdrains. Any such crack or break would allow wash water to boil upwards in a concentrated stream, perhaps seriously upsetting the bed and causing mixing and mounding of the filter gravels.

In plants where sand only is used as a filter media and no surface wash equipment is installed, trouble may be experienced with filter clogging due to bacteria growth within the bed. One effective method of cleaning up such a bed is by heavy chlorination. Apparatus needed is a portable chlorinator, 150 lb. chlorine cylinders and a hand operated piping arrangement which is thrust down into the bed. The piping assembly is made up of a piece of one inch piping about six feet in length having a tee fitting at both ends. Two short lengths of one inch pipe about 14 inches long are threaded into the tee at one end of the six foot section. The outer ends of these are capped and a number of small holes are drilled through each length. This is the end of the assembly which is pushed down into the filter sand for chlorinating. To the tee at the opposite end of the assembly two more short lengths of pipe are fixed to form a handle. The outer end of one pipe is capped as before and the other end is fitted up to take a one inch hose connection. To carry out the cleaning operation, the filter influent valve is closed and water in the bed lowered until approximately four inches remain above the sand. Effluent valve is closed. The portable chlorinator is connected up to water supply and 150 lbs. chlorine cylinder. Discharge from the chlorinator is carried through one inch flexible hose to the handle end of the pipe assembly. Chlorine dose should be about 50 ppm. The pipe assembly is lowered

into the sand about two feet by a man standing in the wash trough and the chlorinated water is carried through the hose to the pipe assembly and exits through the small holes in the bottom pipe sections as high velocity jet streams, cleaning and scrubbing the sand. The assembly is lowered, left for a few minutes and then lifted and moved along the bed in this fashion until the whole area has been so treated.

After this the filter is left as is for 24 hours, then given two or three washes. This treatment is quite effective.

Another method of cleaning sand is by passing it through an eductor, dumping it into another filter and then repeating the process, returning the sand to its own filter. This will effectively clean the sand, but a number of filter washings will be necessary to get rid of the removed dirt.

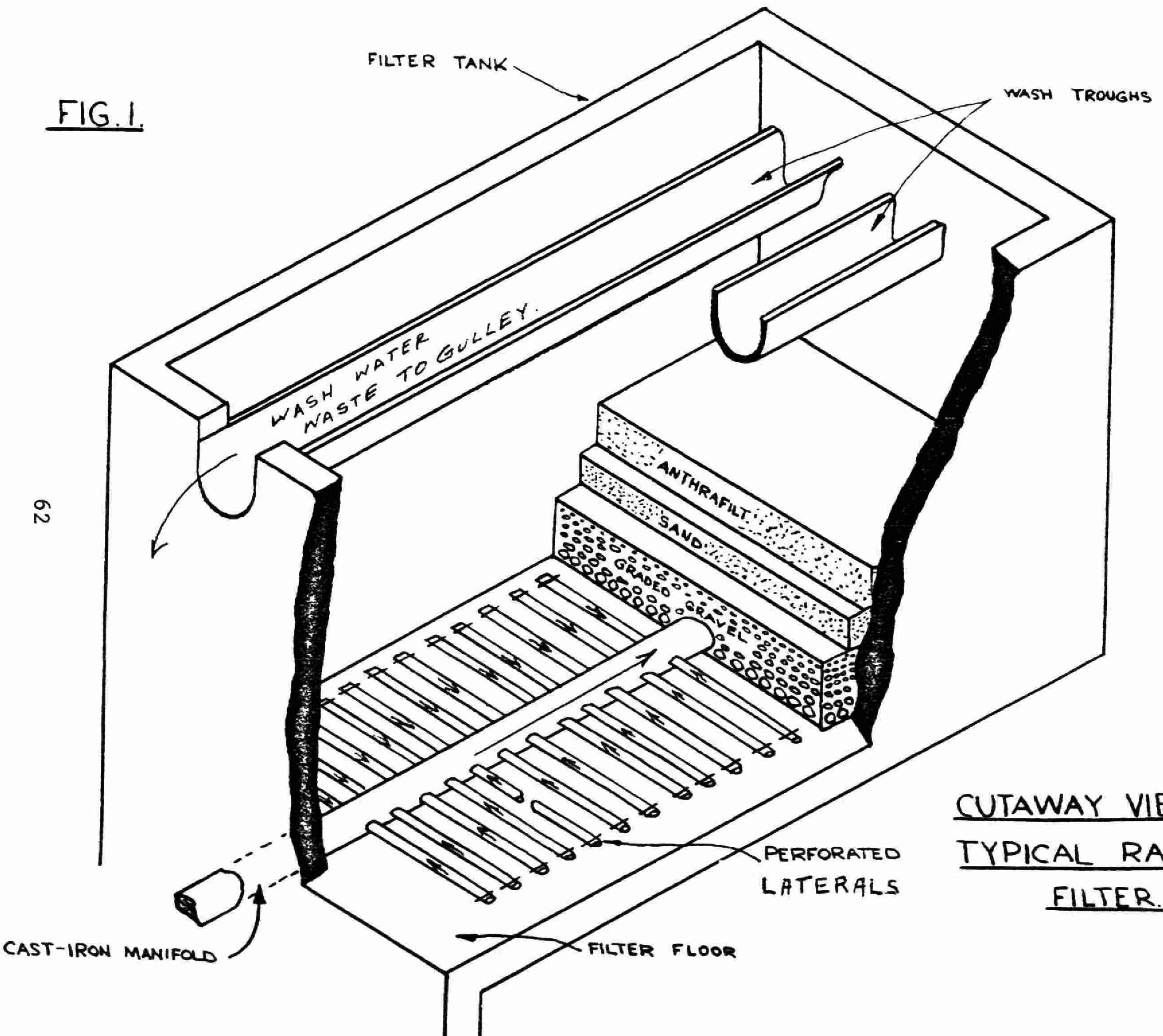
These measures, while being effective are but a temporary expedient. Taking the long range view it will be seen that the installation of surface wash equipment will greatly reduce, if not entirely eliminate, many of these problems. Since their inception, their effectiveness in increasing the overall efficiency of the present day rapid sand type filter has been amply proved.

ANTHRAFILT VS SAND AS A FILTER MEDIA

Anthrafilt has a lower specific gravity, 1.5 as against 2.65 for sand thus requiring a lower backwash velocity.

Being lighter in weight, 55 lbs. per cu. ft. as against 100 lbs. for sand, only about half the quantity is required for a given filter. Anthrafilt is however much more expensive than sand.

FIG. 1.



CUTAWAY VIEW OF TYPICAL RAPID SAND FILTER.

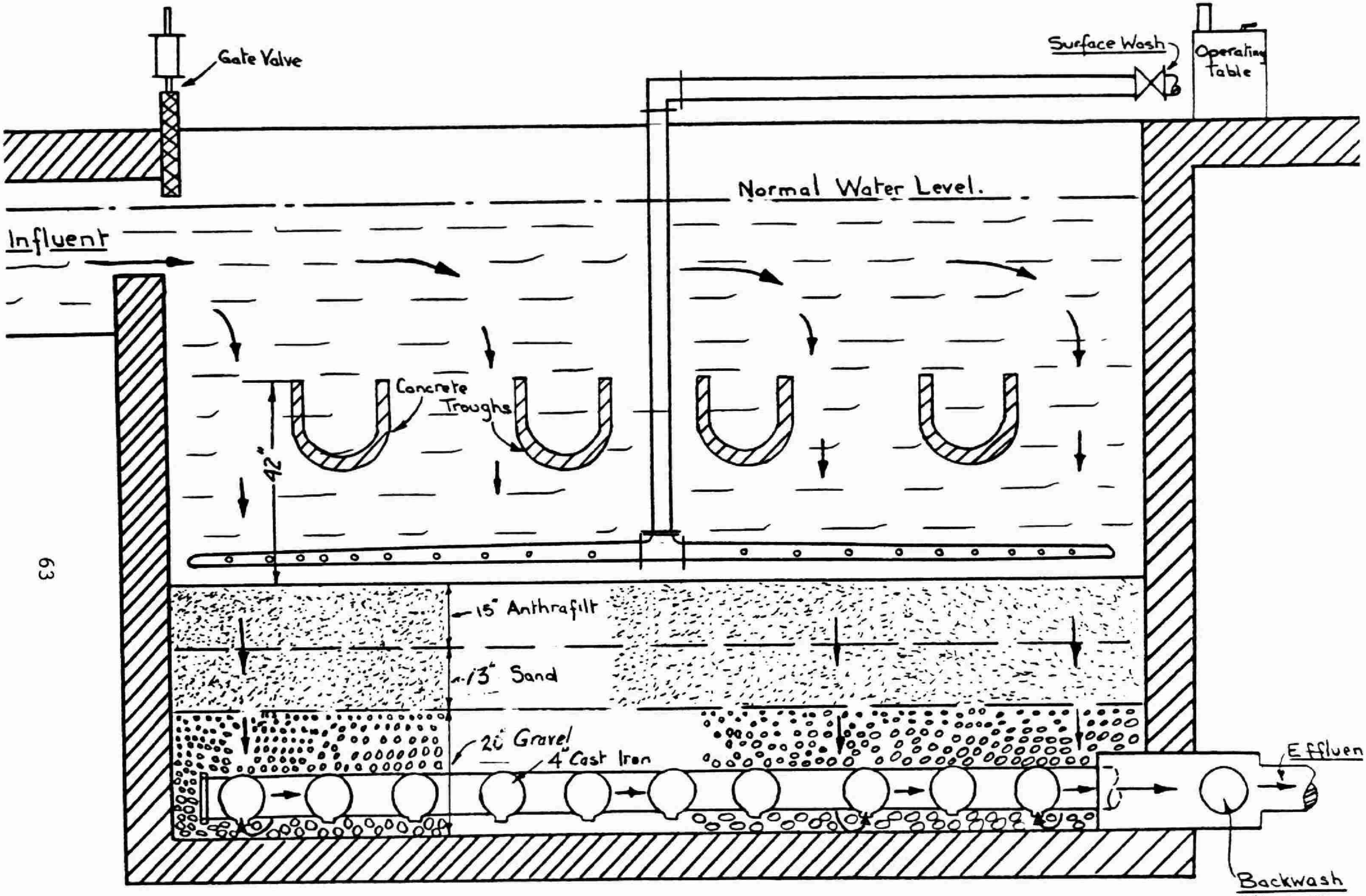


FIG 2

FILTER IN OPERATION

N.T.S.

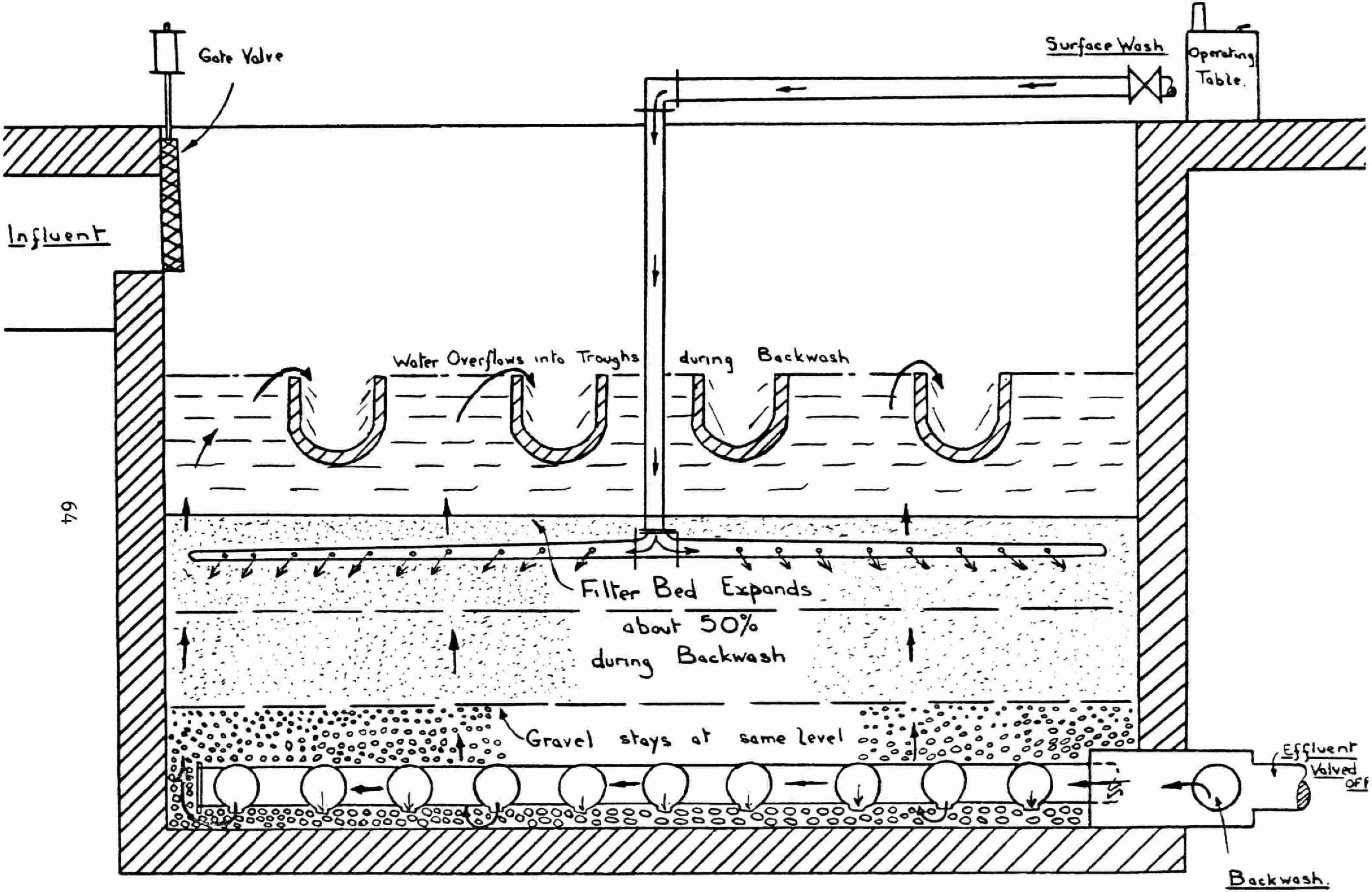


FIG 3

BACKWASHING A FILTER.

N.T.S.

GRAVEL CONTOURS - FILTER NO. 9 - DATE SEPT. 1, 1963

44	44	44
44	43	44
44½	44	43½
44½	44	44

42½	43	42½
43	42	43
43	42½	43
43	43	42½

ALL FIGURES SHOWN INDICATE INCHES FROM TOP OF TROUGH TO TOP OF FILTER MEDIA. (NORMAL - 42") EAST

WEST

45	44	44
45	44	44
45	44	44
42½	43	42½
44	44	42½

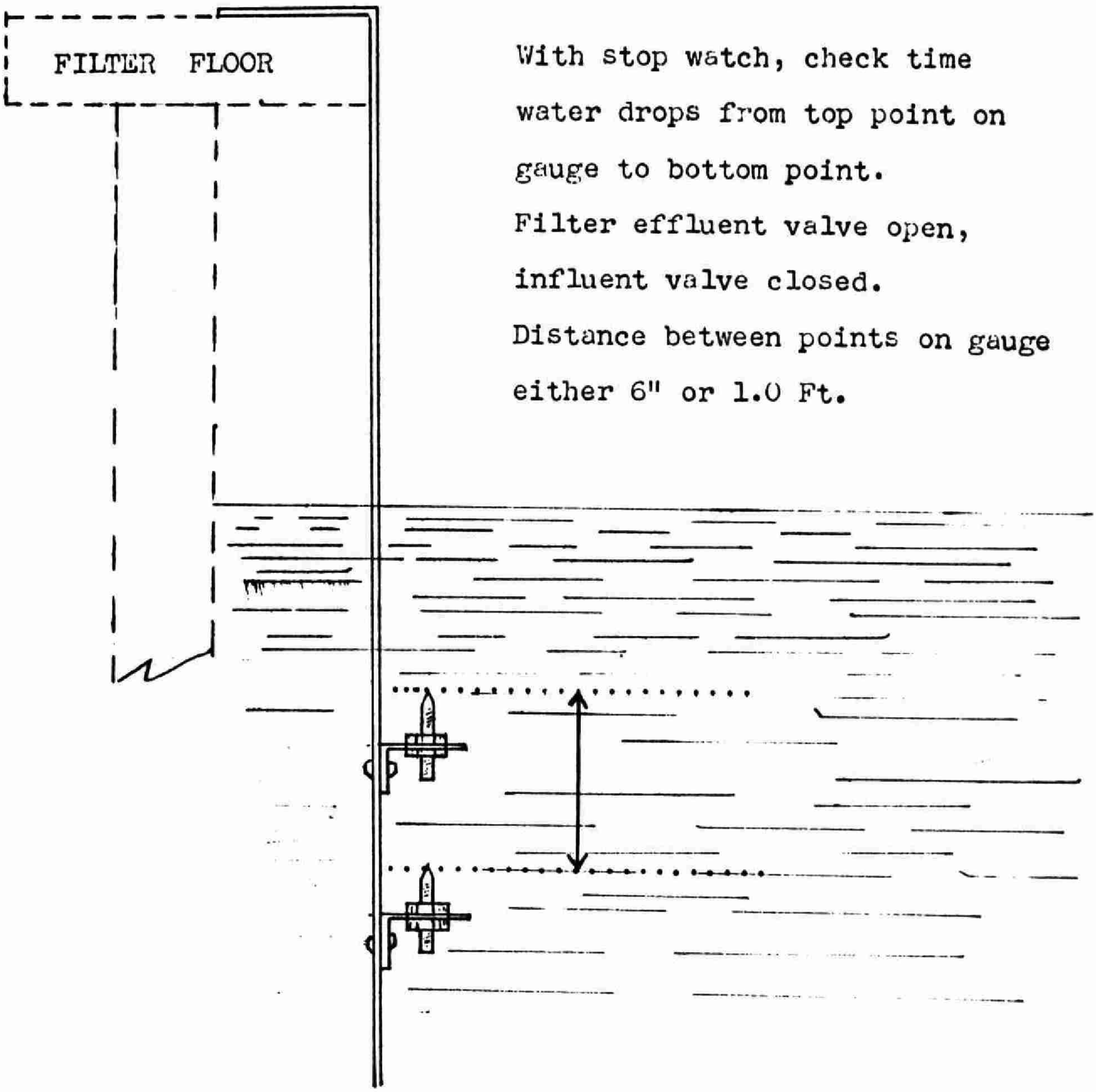
CENTRE LINE OF TROUGH

43½	43	43
43	42½	43
43	44	43½
43	43	42½
43	43	43

NORTH

TYPICAL DATA SHEET SHOWING FIGURES FROM WHICH GRAVEL CONTOURS ARE DETERMINED.

HOOK GAUGE IN USE FOR CHECKING ACTUAL RATE OF FLOW THROUGH FILTER.



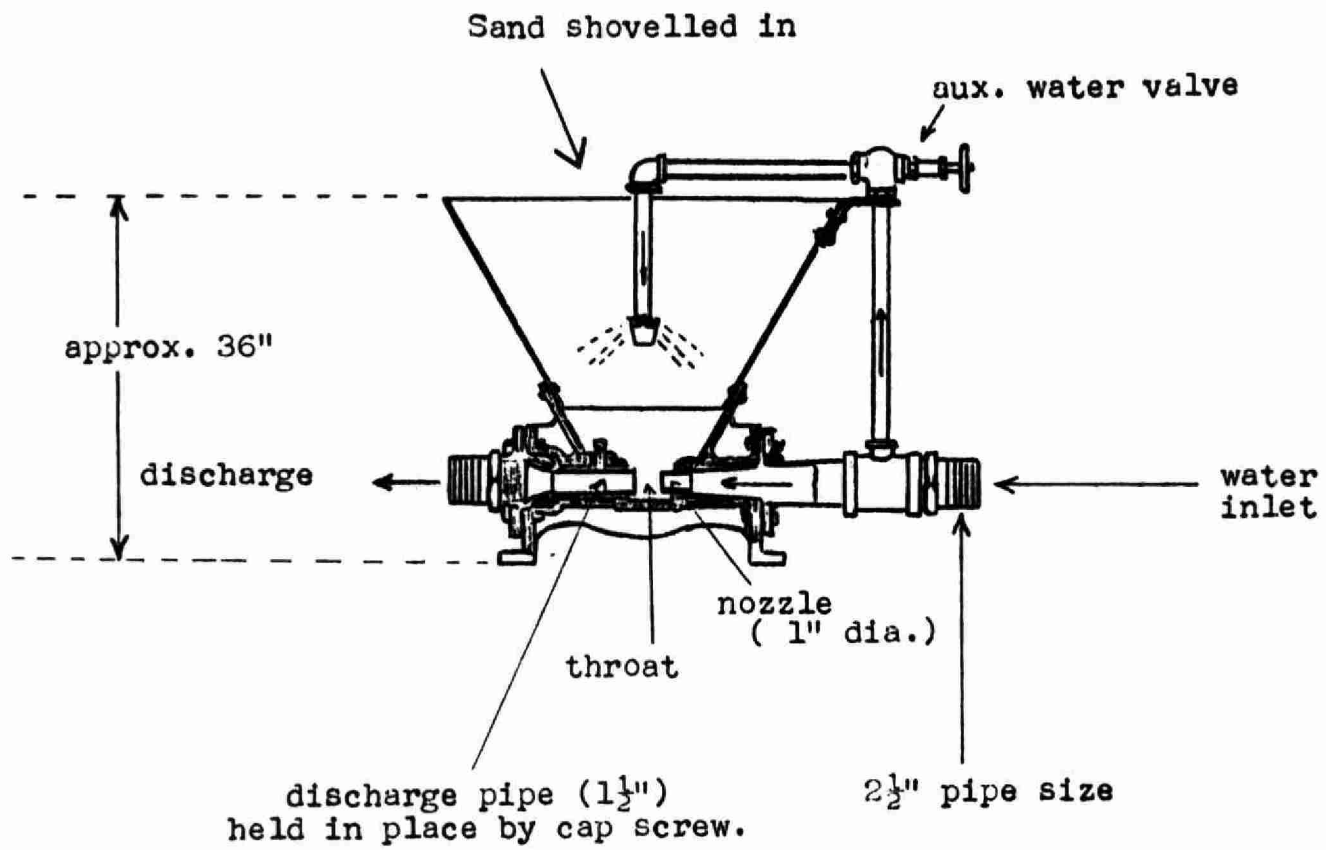
With stop watch, check time water drops from top point on gauge to bottom point.

Filter effluent valve open, influent valve closed.

Distance between points on gauge either 6" or 1.0 Ft.

PORTABLE WATER JET

SAND EDUCTOR



THE CONSTRUCTION AND MAINTENANCE OF DRILLED WELLS

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INTRODUCTION

Ground water is an important source of water supply which is utilized by many municipalities in Ontario. Its efficient development depends upon good well construction and proper maintenance of wells and pumping facilities.

REVIEW OF GROUND WATER TERMS AND CONDITIONS

Before discussing the construction and maintenance of drilled wells it is desirable to review several of the basic terms and conditions concerning ground water.

Ground water is present near the earth's surface in the pore spaces between the grains of unconsolidated overburden deposits and in fractures and pore spaces in consolidated bedrock materials. The term ground water is applied to the water in the saturated portions of the overburden and bedrock materials.

Ground water moves under the influence of gravity from places of higher elevation to places of lower elevation. The movement of ground water through pores and fractures is hindered by friction. The resistance to movement is greater through small pores and fractures and lesser through large pores and fractures.

The level at which ground water rests in a well when no water is being discharged from the well is termed the static level. The static level is described commonly as the distance from the top of the well to the surface of the water. Similarly the pumping level is the level at which water rests in a well at any given time when the well is being pumped, and is measured commonly as the distance from the top of the well to the surface of the water.

The water in a well will be under either water-table or artesian conditions.

A distinguishing feature of a well under water-table conditions is that the static level of the water in the well does not differ significantly from the level where water was first encountered unless the well is particularly deep, except for normal seasonal variations.

The distinguishing feature of artesian conditions is that the water in the well rises above the level at which it was encountered when the well was being constructed. Artesian conditions are created by the confinement of water in a water-bearing formation by an overlying layer of fine-grained material through which water will pass only at very slow rates. The force which causes the water to rise can be thought of simply as the weight of the water from higher portions of the water-bearing formation less the loss in force due to the friction of water moving through pores and fractures. In general water which falls on an area of higher elevation and moves to an area of lower elevation through a water-bearing formation beneath a fine-grained confining layer will be under artesian conditions. Artesian wells flow when the top of the well casing is below the static level of the well.

Some conditions under which wells may be constructed are shown in figure 1.

WELL CONSTRUCTION

Test Drilling

The type of well to be constructed will depend on the geologic and ground-water conditions in the area. The size of the well and the well components will depend on both the amount of water that the well will be required to produce and the geologic and ground-water conditions.

In nearly all areas it is necessary to drill one or more test holes or test wells before the construction of a municipal well can be completed. The test holes or wells provide information on the geologic and ground-water conditions and through the use of pumping tests permit calculations to be made of the quantity of water available at any given site. An equally important function of pumping tests is to determine the chemical quality of the water.

On Commission test-drilling projects test holes or test wells which are designed to end in bedrock are drilled generally with a sufficiently large diameter to accommodate the final pumping equipment and if a suitable supply of water is found the test hole becomes the finished well. This practice is followed because the fractures yielding water in rock wells are very irregular and a larger diameter well has more chances of intersecting such fractures than a well of smaller diameter, and it is necessary to pump the test well at high rates in order to establish the yield of a well at the site.

After the test-drilling programme has been completed the site or sites for municipal wells and the type of construction can be selected. The basic condition governing the type of well will be whether the well will end in unconsolidated deposits of sand and gravel or in consolidated bedrock formations.

Wells Ending in Sand and Gravel Deposits

Many of the large capacity municipal wells in the province obtain water from sand and gravel deposits. The main problem involved in the construction of a well in sand and gravel is to prevent the entry of fine grained particles of silt and sand into the well. This is accomplished by using a well screen to hold out the coarser materials and developing the well thoroughly during construction to remove the fine particles from the sand and gravel formations near the well. Well screens should be selected according to the character of the water-bearing formation and the size of the materials introduced in any gravel pack. Current design practice uses a screen that permits 40 to 70 per cent of the sands and gravels around the well to be drawn through the screen and removed. The yield of a well can normally be increased much more through increasing the length of the screen than through increasing the diameter of the screen.

Many kinds of metals are used in well screens. The alloys generally have a greater tensile strength and resistance to corrosion than the unalloyed metals. Table I lists many of the metals used in well screens together with a summary of the tensile strength and the resistance to corrosion by water and acid treatment.

Table I Properties of Metals Used in Well Screens

Name of Metal	Analysis		Tensile Strength psi Yield	Ultimate	Resistance to Corrosion by water	Acid Treatment
Everdur	Copper Silicon Manganese	96% 3% 1%	90,000	115,000	Very Good	Very Good
Stainless Steel	Steel Chromium Nickel	74% 18% 8%	90,000	110,000	Very Good	Good
Monel	Nickel Copper	70% 30%	75,000	100,000	Excell-ent	Very Good
Silicon Red Brass	Copper Zinc Silicon	83% 16% 1%	72,000	83,000	Good	Good
Super Nickel	Copper Nickel	70% 30%	67,000	69,000	Excell-ent	Very Good
Armco Iron	Iron	99.84%	50,000	55,000	Fair	Poor
Steel	Mang-anese Carbon	.20/.50% .08/.15%	45,000	50,000	Poor	Poor

The two main types of wells used for sand and gravel formations are natural sand and gravel wells and gravel-packed wells. Other names for gravel-packed wells are gravel-filter or gravel-wall wells.

Natural Sand and Gravel Wells

The main components of natural sand and gravel wells are a protective casing which extends from above the surface of the ground to or into the water-bearing formation and a well screen which is set opposite the water-bearing formation. If the water-bearing formation is thick and contains layers of fine grained sediments sections of well screen may be set opposite the coarser materials and blank sections of pipe set opposite the finer materials. The

screen may be attached directly to the bottom of an inner working casing or sealed to the protective casing by means of a lead packer or other commercially manufactured seal. The bottom of the screen should be closed with a plug of cement or the material of which the screen is made.

Natural sand and gravel wells are suitable for coarser grained materials and deposits which contain materials with a good range of grain size.

Components of a natural sand and gravel well and of a gravel-packed and rock well are illustrated in figure 2.

Gravel-Packed Wells

The main components of gravel-packed wells are an outer protective casing, an inner working casing, a well screen set opposite the water-bearing formation and a gravel pack of clean washed gravel introduced around the outside of the well screen.

The protective casing extends from above the surface of the ground to or into the water-bearing formation.

The working casing is attached to the top of the well screen by a welded joint or a threaded coupling and extends upwards either to a point above the surface of the ground or to a point well above the bottom of the protective casing. In order to reduce corrosion the bottom portion of the working casing may be of the same metal as the well screen.

As is the case in a natural sand and gravel well, if the water-bearing formation is thick, blank sections of pipe may be set opposite the finer-grained portions of the aquifer. The screen is attached directly to the bottom of the working casing and the bottom of the screen is sealed with a plug of cement or the metal of which the screen is made.

The gravel in the gravel pack should be composed of well rounded particles which have been washed and sized. The size of the gravel should be selected carefully with reference to the character of the water-bearing formation opposite the screen to ensure a sand-free water supply. Silica gravel has the best resistance to corrosion and is the material most commonly used in gravel-packed wells.

Gravel-packed wells are used not only for coarser grained materials and deposits which contain materials with a range of grain size, but also for finer-grained gravels and sands that have little variation in grain size.

Rock Wells

Rock wells are dependable sources of supply for many municipal waterworks systems. The main problem in constructing a rock well is to provide a good seal between the protective casing and the rock to prevent the entry into the well of clay, silt and other fine particles from the overburden formations above the bedrock. This problem is more difficult when the materials directly on top of the bedrock are water-bearing silts, sands and gravels.

Most rock wells consist of a single protective casing extending from above surface to or into the top of the water-bearing formation.

The main methods used to seal the casing to the bedrock are by driving casing equipped with a drive shoe into the bedrock surface or by grouting an annular space between the casing and the rock in the upper portion of the bedrock formations. If these methods do not prevent the entry of overburden materials it may be possible to install a liner inside the protective casing which will extend below the bottom of the protective casing and be sealed to the rock portion of the well by a lead or other commercially manufactured packer. Cement grout may be introduced in the annular space between the liner and the bedrock.

Flowing Wells

Great care must be exercised in constructing wells which end in artesian formations that possess sufficient pressure to flow above the surface of the ground. In the construction of such wells the initial drilling operations should extend into, but not through, the impermeable formation confining the water under artesian head. Then the protective casing should be installed and grout pumped into the annular space between the casing and the walls of the hole. Ample time should be allowed for the grout to set before drilling proceeds into the artesian formation. The drilling operations into the artesian formations are continued in a normal manner.

Water Quality

The water from many wells obtaining water from sand and gravel deposits has an iron content in excess of the recommended maximum of 0.3 ppm. This is the most common quality problem encountered in sand and gravel aquifers. Such water requires iron-removal treatment to ensure satisfied customers.

Rock wells present a greater variety of quality problems which should be determined during the pumping tests. Care should be excercised to be sure that the water wherever possible does not have a chloride content in excess of 250 ppm. The water from rock wells in Ontario generally is very hard and in nearly all cases no treatment is provided for the hardness. Quality problems which may require treatment are high contents of hydrogen sulphide or iron or a combination of these. Coliform bacteria may move considerable distances through bedrock formations from locations where the bedrock is close to surface to the sites of municipal wells thereby requiring chlorination treatment for the well water.

The advantages common to most well supplies are constant low temperature, freedom from turbidity and colour problems and general freedom from taste and odour problems.

Wells should be provided with a sanitary seal of cement grout or concrete extending from the land surface to a sufficient depth to prevent the seepage of surface water or other contaminating materials down the outside of the casing into the water-bearing formation.

MAINTENANCE OF WATER WELLS

Water Level Records

Accurate records of static and pumping levels in water wells are essential aids for determining if and when maintenance is required. Every municipal system utilizing ground water should have a well planned programme for the measurement and recording of water levels and the amounts of water pumped for each well.

If the static level of a well remains essentially the same, but the pumping level shows a steady decline it can be deduced that the openings through which water enters the well are being plugged and the well should have suitable maintenance. On the other hand if both the static level and the pumping level in a well show a steady decline it can be deduced that the well is withdrawing more water than the amount entering the area of influence. If this trend continues it may require re-setting the pump at a lower level or constructing other wells suitably spaced to provide additional water without interfering seriously with the existing well.

Deposits in Wells

Ground water may carry sizable quantities of bicarbonates, sulfates, and chlorides of calcium, magnesium and sodium in solution. Often present although in smaller quantities are compounds of iron, manganese, silica, nitrate, fluoride and other elements.

Pumping a well reduces the pressure in the well by an amount equivalent to the drawdown. This reduction in pressure plus an increase in velocity of the water entering the well releases some carbon dioxide from the water and reduces the ability of the water to carry dissolved minerals in solution. Minerals such as iron hydroxide, calcium carbonate and magnesium carbonate are then deposited in the pump, in the well screen openings, in the gravel pack and on the sides of a rock well. Direct deposition of suspended matter from the water may also occur. Such deposits can often be removed by one or more methods which will be discussed under the general heading of well stimulation.

Well Stimulation

Well stimulation is defined generally as the treatment of a well by mechanical, chemical or other means for the purpose of reducing or removing an underground resistance to flow.

With the different types of water wells and the wide variation in the composition of deposits formed in wells no single treatment is suitable for all wells. In most instances it would be wise for municipalities to obtain the advice and services of water-well experts before embarking on a well stimulation programme.

Some methods of well stimulation which have been used for water wells will be described briefly. Table 2 outlines the application of the methods to various problems.

Table 2 - Applications of Various Well Stimulation Methods

Method	Unconsolidated Aquifers	Limestone or Dolomite Aquifers
Surging	Removes plugging deposits of clay, silt and fine sand in areas adjacent to screens	Rarely used
Jet Cleaning	Removes encrusting minerals, clay, silt and fine sand in areas adjacent to screens	Rarely used
Dynamiting	Vibratory explosion may be effective if carefully used	Effective under some conditions
Hydraulic Fracturing	Not usually used	Particularly effective in rocks with tight fractures
Acidizing	Removes iron, sulphur and carbonate deposits	Sometimes beneficial, best results obtained by pressure acidizing
Caustic Soda	Removes oil scum left by oil-lubricated pumps	Removes oil scum left by oil-lubricated pumps
Chlorination	Removes iron and slime-forming bacteria	Removes iron and slime-forming bacteria
Polyphosphate followed by chlorine	Removes fine silt, clay, colloids, disseminated shale and soft iron deposits	Not usually effective

Surging

The process of surging involves the movement of water back and forth through the formation surrounding the well in an effort to remove the fine particles clogging the walls of the well. Surging can be accomplished by the use of a surge block, compressed air, dry ice, or by starting and stopping a pump. Surging is often used in conjunction with chemicals to increase their effectiveness.

Jet Cleaning

Jet cleaning is done by directing a high-velocity stream of water horizontally out through the openings of well screens to move the formation particles and encrusting materials surrounding the well screen. It is desirable to pump the well lightly at the same time that the high-velocity jet is operating to aid in carrying the loosened material into the well for removal. Jet cleaning may be used instead of surging in conjunction with the chemical treatment of wells.

Dynamiting

The use of dynamite for stimulation should only be done by persons qualified for the job.

A series of dynamite charges may be set off at frequent intervals along the length of the water-bearing rock or a high-velocity explosive fabricated in the form of a string may be used to produce a linear explosion along the whole length of the water-bearing rock.

A special form of dynamiting known as vibratory explosion uses a series of very small charges fired in rapid sequence to produce a vibrating effect. The explosion creates a gas bubble which expands and contracts and adds a surging action to help free the particles loosened by the vibrations of the explosion. This method can be applied to screened wells in addition to rock wells, but such use must be carefully planned and carried out to avoid damaging the screen.

Hydraulic Fracturing

Hydraulic fracturing is a new technique which was first introduced into the oil industry and has been used on thousands of oil wells. It consists of injecting fluid into the well under such high pressure that the rock formation is actually parted or fractured. Sand is added to the fluid and remains in the fractures propping them open permanently.

Acidizing

This is a popular, and in many cases, an effective method of stimulating wells. It is especially well suited to the stimulation of sand and gravel wells in which the screen is encrusted with iron and carbonate deposits.

The most commonly used acid is muriatic, a commercial grade of hydrochloric acid. The concentration usually injected into the well is 15 per cent. Muriatic acid should not be used in wells containing concrete screens. An inhibiting agent should be added to the acid before use in order to delay attack on the metals in the well structure. In time the protection provided by the inhibitors is broken down so it is important that the acid should not be allowed to remain in the well for prolonged periods. Other additives for the acid include antifoam and stabilizing compounds. Stabilizing chemicals prevent the secondary precipitation of dissolved iron deposits which could plug the screen.

A saturated solution of sulfamic acid has been used recently in place of muriatic acid for acidizing wells. Sulfamic acid has the advantage that it can be shipped in a granular form and the acid solution made up at the well site. The rate of attack on metals is slower than that of hydrochloric or sulphuric acids. Nevertheless a suitable inhibitor should be used. Iron oxide scale is only partly dissolved by sulfamic acid, although the addition of sodium chloride increases the effectiveness in dissolving iron deposits.

Pressure acidizing is receiving study as a method of stimulation of water wells ending in rock or cemented overburden deposits. It consists of the introduction into the water-bearing formation of large volumes of acid at high rates of injection and pressure. Pressure acidizing can be applied only when the formation to be treated is sealed off from overlying formations.

Polyphosphate Treatment

The use of polyphosphates for well stimulation is generally confined to sand and gravel wells. They can be used successfully for cleaning screened wells which are plugged with fine sand, silt, clays, colloids, disseminated shales and some other mineral deposits. The polyphosphates react with, and hasten the removal of, these materials. Polyphosphates can also be used to dissolve certain forms of soft iron deposits. Wetting agents may be used in conjunction with polyphosphates to improve the penetration into the formation. Polyphosphate does not readily attack the metals in wells.

Polyphosphates should not be used in the treatment of wells with multiple screens in water-bearing formations containing layers of clay or silt as the action of the polyphosphate will cause the clay and silt to move into the sand and gravel formations, plugging them.

Chlorination

Chlorine is sometimes used alone as a complete well treatment, but it is more frequently used as a supplement following an acid or polyphosphate treatment. A concentration of 50 ppm of available chlorine in a well provides effective disinfection, a concentration of 200 ppm destroys certain types of iron bacteria, and a concentration of 500 ppm will destroy sulphur and slime bacteria.

Effects of Well Stimulation

Louis Koenig, who recently completed a three year study of the benefits of water well stimulation, concluded that stimulation is a technically and economically feasible practice applicable to a wide variety of wells and aquifers and that by means of stimulation additional production can be obtained from existing facilities, the investment cost per unit of production can be reduced and the energy cost for pumping water can be reduced. He advocated that studies in the field of well stimulation should be greatly increased.

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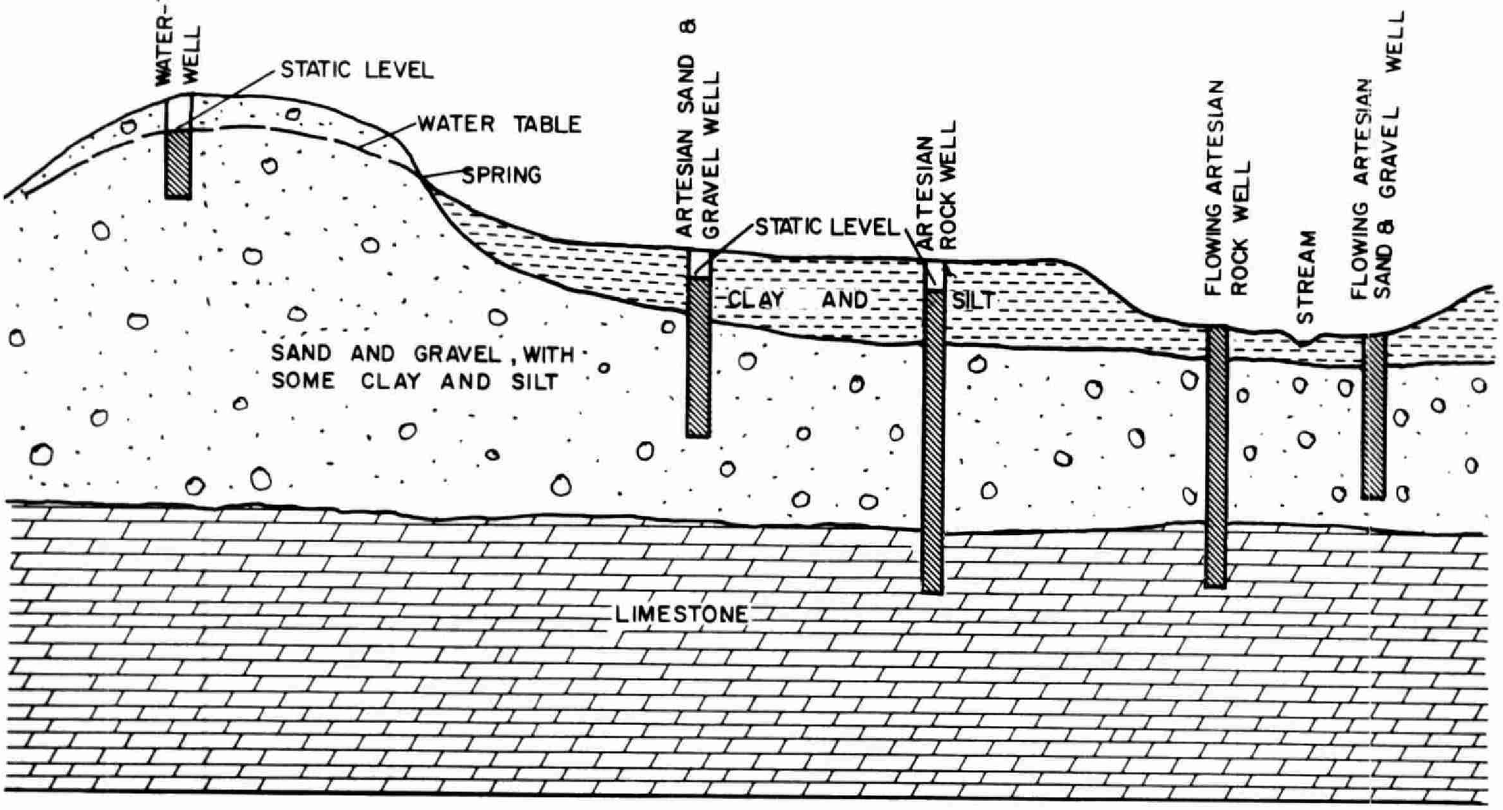

FIGURE 1. ILLUSTRATION OF WELLS COMPLETED IN OVERBURDEN AND BEDROCK FORMATIONS AND UNDER WATER-TABLE, ARTESIAN, AND FLOWING ARTESIAN CONDITIONS.

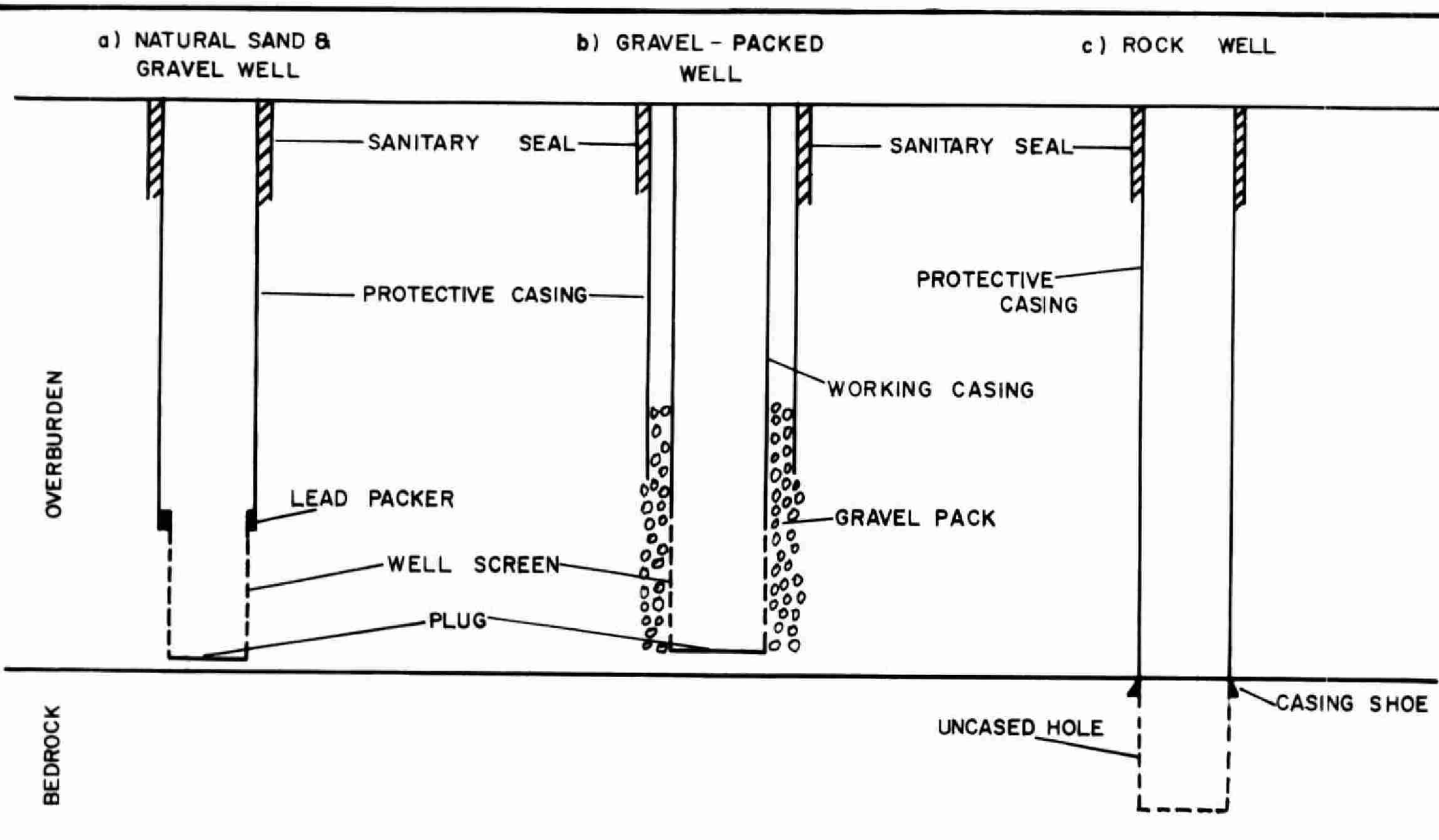

FIGURE 2. COMPONENTS OF SOME TYPICAL TYPES OF DRILLED WELLS.

WATER DISTRIBUTION SYSTEM MAINTENANCE

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INTRODUCTION

I assume that all of you have attended the Basic Water Works Course, and therefore have retained the lecture on Distribution System Maintenance. Therefore, I shall be attempting to avoid any undue duplication of presentations relative to that paper and any other associated paper on this course. I would like to recommend to you the manual published by the American Water Works Association AWWA M8 -"A Training Course in Water Distribution", as being a good source of information on this subject.

The distribution system has been described variously as consisting of the distribution mains, valves, hydrants, service connections, meters, booster pumping stations, and distribution storage facilities.

Consumer dependence on an uninterrupted adequate public water supply has grown almost beyond belief within the past two decades, and adequate maintenance will be required to keep the system in a condition suitable to retain good relations with the consumer public. The person responsible for the functioning of these units, therefore, must be familiar with the means and methods to maintain them properly.

MAINTENANCE PROGRAM

The maintenance program then consists of two phases: anticipating normal depreciation by routine checks and preventative procedures, and being organized to handle a distribution system crisis such as a break in a watermain, by corrective maintenance. Such a program is necessary to:

1. Prevent failure of facilities
2. Detect and eliminate weak links in the system
3. Determine the type and quantity of materials and replacement parts to be stockpiled for repairs

4. Analyze how distribution facilities stand up in actual operation as a guide for future installations
5. Maintain good public relations by making needed repairs before damage and interruption to service occur
6. Detect and eliminate safety hazards
7. Distribute work load more advantageously
8. Reduce the cost of maintenance.

The best maintenance aid, of course, is a proper initial installation. For instance, if all watermains were laid by hand on a shaped bottom of undisturbed soil, there probably would be fewer breaks and inconveniences. However, with increased labour costs, machine digging predominates and this does not lend itself economically to a shaped bottom. Rather, loose material is usually added to the bottom of the trench and it is intended that this is compacted under and around the pipe to provide an adequate bearing medium.

DISTRIBUTION MAINS

Of necessity, the maintenance staff is concerned with quickly repairing any subsequent leaks or breaks in order to maintain service.

I think that it is also advantageous to have some knowledge of the apparent causes of main breaks when repairing these.

The cause of pipeline breaks is a continuing assessment and one on which all principals are not agreed. Often, this has been aggravated by the lack of proper assessments of the initial conditions found at the repair excavation. It would appear, however, that in frost areas, the greater number of breakages result from a cumulation of forces and the larger percentage occur during the winter months, in the early hours of the morning, when main pressure is usually at its greatest value.

In surface water supply systems the temperature of the water may vary from over 70°F. in the summer to 32°F. during the winter. The temperature of ground water supplies does not vary so appreciably. At the time in the year that the water experiences its most rapid drop in temperature, it causes the watermains to attempt to appreciably decrease their individual lengths. If the joints are rigid, such as those bell-and-spigot joints where sulphur compounds were used, the pipe is restrained from this shrinkage and is held in tension. This is not

sufficient in itself to cause fracture, but with an assist from corrosion-thinned walls, beam action from a point of pressure such as a rock in the bedding, cantilever action from frost or voids and metal fatigue from repeated flexure due to vibration, etc., fracture may result. If the frost penetrates to the main, vibration from traffic loads can be transmitted directly thereto. Disturbances due to other underground construction as well as water hammer, also can induce fracture. In small pipe sizes, the beam or cantilever stress usually predominates and results in a circumferential break. Larger sizes usually fail due to ring stresses and fracture longitudinally.

The circumferential break can sometimes be repaired with split repair sleeves without dewatering the main. There is a multitude of repair sleeves and clamps for this purpose on the market which were originally considered only temporary measures but which have now proved themselves to be worthy of being considered as permanent repairs.

The longitudinal break, depending upon its severity, may necessitate dewatering the main and the insertion of a plain end section.

The prime intent is to excavate and repair the main as soon as possible, and then restore it, using proper methods to avoid a future fracture there. The soil should be well compacted under and around the pipe in the proximity of the repair. Granular material would be desirable here while a further preference would be to use 3/8" crushed stone, since it is less effected by water in the trench.

As I have stated above, the rigid joint appears to have been one of the worst offenders in surface water supply system breaks in frost areas, and the advent of rubber joints for water main construction should tend to reduce the percentage of breaks. It is important with these joints, however, to preserve adequate blocking or strapping for the full thrust that is to be developed on any bend, change of direction or end of the line.

Active interest is being shown in the use of ductile iron for pipe in water distribution systems. Possibly the advent of standards for pipe of this material will accelerate its usage.

Some poured bell-and-spigot jointing materials have tended to expand over the years to rupture the bells. These can

be repaired with bell repair clamps or by cutting in a piece of plain end pipe. When this trouble can be anticipated it may be preferable, particularly if paving is imminent, to replace these known trouble joints even prior to their rupture.

DISTRIBUTION VALVES

The number and location of fully operative valves in the system will predicate to a great deal, the degree of inconvenience that will be suffered by the customer at times of repairs. It would be difficult to find a water distribution system where a surplus of valves had been installed. Valve manholes or vaults on the mains are desirable, but financial considerations usually predicate their use only on those valves in excess of 10" in diameter, or in special locations.

Little can be done to maintain the buried valve without excavation, except for operating it, preferably annually if over 12" diameter and once every three years if smaller. But even this alone can often prevent it from becoming inoperative, as well as confirming its operating details. Since most of these valves are of the gate type and constructed of dissimilar metals, galvanic corrosion can take place at the moving faces. Without operation of the valve, the by-products of this corrosion will ultimately seize these faces and render the valve inoperative.

It is desirable to have all main valves open with the valve stem turning in the same direction. Where a valve opens in the opposite direction, to the majority, some indication at the site is sometimes given, such as painting the underside of the valve box top a bright colour. Power tools for valve operation can assist in any major maintenance programme.

The valve stem is attacked by corrosion and without operation will ultimately seize and can result in a broken stem. The packing can be softened by the application of kerosene or other lubricant, and the number of turns, right or left to open, should be checked each time to avoid undue torque being applied.

Blockages can sometimes be flushed from the valve by partially closing the valve, closing an adjacent main valve, and opening a hydrant between these two. Unauthorized personnel should be prevented from the operation of the valves.

A common problem has been the inability to engage the key due to stones having been placed in the valve box by children. Lock-type tops have been developed, and I have one of these for your inspection.

Valves in vaults are more easily maintained, and in some instances, can be partially rebuilt without removal. Gland leakage during operation is not considered serious, but continual leaking requires attention. I understand that an extensive valve maintenance presentation is made in another of your lectures so that I would wish at this time only to refer you to that lecture.

Inspections are required of all street improvement projects to ensure that all valve boxes and vault tops are in position and properly graded. Stakes are sometimes of value to indicate the original position of known valves, and their boxes. This is an opportune time also to install new packing or additional valves before paving is completed.

It is also important to retain and uncover if necessary, all these units after any paving or resurfacing has been completed.

MAIN CLEANING

One of the most important maintenance operations is that of maintaining the carrying capacity of the mains. Corrosion and encrustations or slime formation in waterlines often causes a serious loss in main carrying capacity and pressure. Cleaning, or cleaning and lining, are the maintenance operations to be performed, as an alternative to laying new mains.

The severity of internal corrosion can be continually assessed by examination of the coupons removed during tapping valve-and-sleeve installations and also by observing the pipe removed from break locations.

A chain-head auger and a scraper-type cleaning tool are usually used.

The chain-head auger is essentially a steel rod which has short lengths of chain attached to it. On the end of each chain is a heavy metal weight. The steel rod is rotated at speeds between 300 and 1000 r.p.m.

The scraper-type tool, commonly called a "pineapple", consists of several discs strung on a flexible rod, and anchored front and back. Extending from the circular edge of the discs are rectangular steel scrapers bent at the ends. In some instances this tool is allowed free travel, propelled by hydraulic action. However, the chance of subsequent blockages necessitating excavation sometimes suggests that this tool is better controlled when pulled through the pipe sections by a power winch.

Pits are dug at both ends of the pipe section to be cleaned, and the desired lengths of pipe are cut out with a power saw. Pumps are commonly used to remove the water accumulating in the downstream pit.

Pipe cleaning is usually followed by continuous chemical treatment of the water supply by glassy hexametaphosphates (Calgon), or more commonly by installing a cement lining in the pipe. In the small sizes, this is done by placing sufficient cement mortar in the pipe line, so that a following mandrel will apply the required thickness when it is pulled through the pipe, behind this mortar.

In the larger pipes, an operator in the pipe directs a machine which sprays a concrete mixture on the walls, and rotating trowels smooth it to a proper value.

I have acquired a short film on water main cleaning and I would propose to show it to you now.

HYDRANTS

In most water systems, hydrants are the only parts of the system which are in evidence to the public and a neat appearance will provide public admiration. This requires proper painting maintenance and reflecting paints appear to be gaining favour, with indications given on the hydrant also, of the main's size or capacity. This painting is commonly performed approximately every two years.

Whereas it would be desirable to use the hydrant for only fire-fighting purposes, other demands are often made of it and it is usual to allow the judicious use thereof, upon acquiring

a permit for a nominal sum. Sometimes an added flat rate is applied or a temporary water meter is installed. To avoid damage to the hydrant by improper and repetitive opening and closing, it is desirable to install an auxiliary valve on one of the hose nozzles and have authorized personnel using the proper wrench, open and close the hydrant only at the start and end of the required period of use.

Wherever possible, this water should be drawn from dead-end hydrants to assist the flushing thereof.

It is desirable to have gate valves located on all branch connections to hydrants, but financial situations may preclude these in the initial installation. Although most hydrants are now designed to allow replacement from the surface in the incidence of damage from vehicles, etc., the flow to the hydrant usually must be cut off later to allow examination of the main valve components. A program of auxiliary gate valve installations can be inaugurated, particularly using equipment allowing valve installation under pressure. Valving hydrant branches in all industrial and commercial areas, as well as on mains over 10" in diameter, should be a first consideration.

Hydrants always should be set on a block on undisturbed ground, adequately braced, and, if self-draining, should be provided with a drainage pit of 3/4" crushed stone approximately 2' in diameter, 2' deep, and to about 6" above the waste opening, with a building paper cover. Other equivalent pits also would be acceptable.

In sewered areas, the sewer trenches act as drains and the water table is usually low enough to allow the hydrant drain holes to operate correctly, particularly if adequate gravel or crushed stone has been placed around the hydrant. In non-absorptive soil or where the water table is high, protection must be taken to avoid freezing of the hydrant and thus rendering it unavailable for fire-fighting purposes.

Connections from the drain holes or drainage pits to sewers usually are not acceptable since this may be considered to be a cross connection.

In areas where poor drainage conditions persist, there appears to be merit in plugging these holes and relying on adequate pumping of the hydrants. This work is facilitated by the exhaust powered hydrant pump which the Township of Etobicoke was kind enough to loan me today, and which you see here. This has previously been illustrated in the November 1959 issue of the Water Works Digest, and appears to have been first utilized by Mr. R. Spark, general foreman of the Welland Board of Water Commissioners.

If the drain holes are not plugged on these problem hydrants, an antifreeze compound, but preferably not salt due to its corrosive tendencies, is added, together with other insulating procedures. Frequent re-inspections, possibly twice a week depending on frost intensity, are required, particularly since the solutions may become diluted with ground water and have their antifreeze properties reduced.

Steam generators usually are used to thaw hydrants and are often sent out on all winter fire calls. When freezing below the valve takes place, the hydrant should be thawed daily. Some flushing may help to keep the hydrant and the branch line from freezing. The fire department should be advised of any inoperative hydrants and also preferably these should be so indicated on the site.

With the advent of the decreased price differentials, the trend appears to be towards the increased use of the more efficient and more easily maintained compression-type hydrant.

Hydrants should be checked two to four times a year, preferably in the spring and fall and also after each use. Naturally, however, the problem hydrants will become known and should be accorded the more frequent inspections, probably daily, during winter months. Points to check are the stuffing box (unless O rings are used), valve, valve seat, barrel (for cracks), opening of the drain port (if not purposely plugged), threads, geared opening mechanism and gaskets - the methods used, depending upon the make of the hydrant. It should be remembered that hose nozzle caps should not be replaced immediately in order that the water may drain from the hydrant barrel. The valve should be opened and closed slowly to reduce the occurrence of water hammer. These inspections should also ensure that householders have not built fences or changed lawn grades which now conflict with the

operation or frost-resisting ability of the hydrant. The hydrant must be clearly visible at all times and this may necessitate the attaching of poles and metal flags during snow periods in some areas.

A correct inspection procedure is as follows.

1. The hydrant should be sounded for leaks.
2. It should be operated and flushed, the ease or difficulty of operation noted, and any worn or loose parts remedied.
3. The condition of the drain valve, operating nut, nozzles, nozzle caps, chains, packing, and paint should be noted.
4. After operation and closure, the interior should be observed to see if the barrel drains properly.
5. The setting of the hydrant and the distance of the nozzles from the ground and curb line should be noted and remedied if not acceptable.
6. The hydrant should be lubricated.
7. The accessibility of the hydrant, ground clearance and interference from poles or other objects should be noted and corrected if necessary.

SERVICE CONNECTIONS

Drilling and tapping mains for service connections is required of most water works maintenance forces. This is usually done while the main is under pressure. Care should be taken to provide a sound connection and to avoid damaging the pipe itself. The attaching chain should be well tightened to prevent slippage of the machine and subsequent drill breakage. It is desirable to have the tools sharp and so avoid bruising the pipe to cause hairline cracks. Mueller or corporation threaded corporation stops are preferable, due in part to extra strength at the thread termination.

When tapping cement-lined, or asbestos-cement mains, drills with tungsten carbide tips will last a good deal longer than the ordinary drill used for cast iron.

Frost action tends to bear on the main and if the connection is rigidly attached rather than with a goose neck, the beam or cantilever forces on the pipe usually result in rupture of the connection.

In most instances, the trend appears to be to use a saddle rather than a branch connection when the required service is more than one-quarter of the nominal main pipe size. Certainly weakening of the pipe by an improper stop installation is to be avoided and to this end, tapping at 45^o to the horizontal is preferable.

Copper is the material most commonly used. If a break occurs between the corporation stop and the curb stop, repairs can be assisted by temporarily freezing the service by means of dry ice or a commercial fire extinguisher. Care should be taken to avoid undue exposure to the CO_2 fumes.

BOOSTER PUMPING STATIONS

These will require maintenance similar to that described in lectures by those others on the course dealing with similar plant matters.

METERS

I believe that meters will be discussed to some length in another lecture during the course.

DISTRIBUTION STORAGE

Distribution storage facilities consist of several types, but I shall mention here just elevated steel tanks and standpipes.

Generally, the life span of these is limited only by damage due to corrosion of the tank plates and the supporting tower, if any. The cleaning and painting of the inside and outside of these tanks as necessary, is the most common and best protection. The tanks should be drained and inspected in the spring, preferably each year, and not exceeding 2-3 years. Periodically an unbiased report should be obtained of the total maintenance work required, such as sandblasting, welding, etc. Since the work on these units is rather hazardous, it is usually performed by a reliable contractor experienced in this type of work.

It should be noted that adequate ventilation should be provided while men are painting inside the tank. These men should

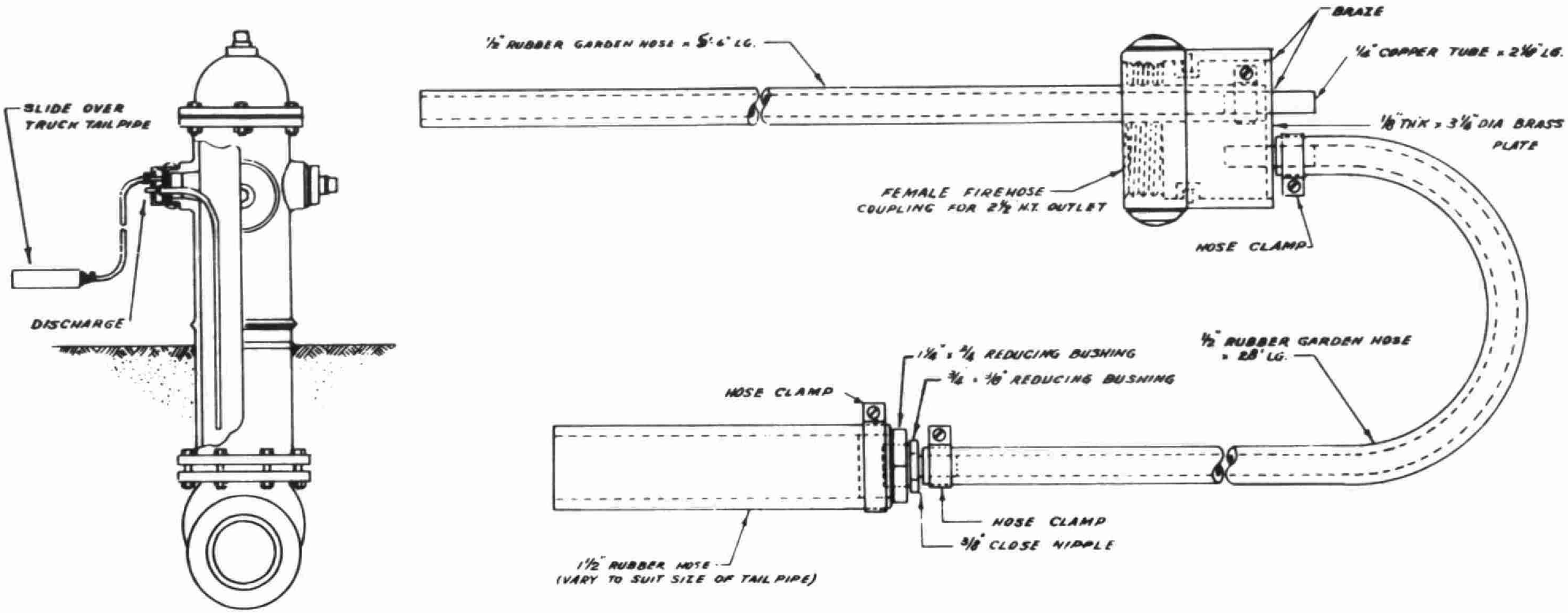
be given a physical examination prior to commencement of the work, and the tank should be sterilized and drained to waste prior to being returned to service.

The outside of the tank and its supports should be inspected for possible structural damage also after every serious storm.

SUMMARY

Time is becoming an ever important factor in the repair and restoration of service disrupted due to main pipe breaks. Two-way radios, standby personnel, and closer valve spacing will probably be required of the maintenance department. With increased labour costs a greater number of expensive labour-saving machines should now be considered.

Considerate investigations of all consumers complaints will be required to maintain good public relations between the maintenance department and the consumer, which is one of the prime aims and requisites of any water works department.



EXHAUST POWERED HYDRANT PUMP

APPLICATION OF TASTE CONTROL METHODS ON WATER SUPPLIES

L. South

District Engineer - OWRC

INTRODUCTION

People tend to become used to the taste or odour of a water and as long as the quality and intensity in this regard is constant, few complaints are received from the natives. However, visitors may object strenuously to such a condition and water of this nature is not likely to attract new water using enterprises to a municipality. In addition, many laymen associate unpalatability with unsafe water.

A survey conducted by Sigworth of 241 water treatment plants, in the United States, reporting taste and odour problems indicated that carbon was effective in 86% of the cases, followed by chlorine dioxide with 25%. For this reason carbon treatment only will be discussed at this time and chemical oxidative methods will be discussed in the subsequent lecture.

SAMPLING

Samples should be taken as often as experience indicates that a change is likely to occur. It is also possible to make this period agree with the flow through time in the sedimentation basins. On an average, samples can be drawn every four hours from the following points; raw water, settled water, filtered water and tap water.

The sampling bottles should be wide-mouthed with glass stoppers. These should be carefully cleaned and rinsed with odour-free water immediately before sampling. The samples should be stored in a cool dark place until the time of testing.

THRESHOLD ODOUR TESTING

When it is desired to have close control on the problem the threshold odour test should be used. This test is merely a dilution of the odour bearing sample with odour free water to the point where the odour is just detectable. That is, if the sample requires dilution to 10 times its original volume, then the threshold number is 10. The test is outlined in Standard Methods and will be further discussed by other lecturers.

This test is quite useful in experimenting with various chemical dosages on a sample of the raw water. It is important in testing that the operator define the odour as well as applying a threshold number. This is necessary so that the treatment efficiency can be compared for different types of odours.

APPLICABILITY & OPERATION DATA

Carbon should in general only be considered at plants having filters. This is in order to prevent the discharge of the material to the distribution system. In addition, the filters should be in good condition and frequent checks made for carbon in the filtrate. The maximum dosage of carbon permissible will vary at different times. Factors affecting this will be the efficiency of coagulation, i.e., in warmer weather with better coagulation and settling larger amounts of carbon can be used. Another point is to filter to waste for a short period after backwashing. This will allow some "alum gel" to build up on the filters and more effectively hold carbon particles. The carbon impregnated gel will provide a continuing adsorptive mat to the taste and/or odour waters. In addition, more care must be exercised for coarse-grained filters.

POINTS OF APPLICATION

Carbon can be applied at any one or combination of the following points; raw water or mixing basins, influent to settling tanks, effluent of settling tanks, and directly to the filters. In any case points of application should be chosen which will allow intimate mixing of the carbon. It is generally found that a split treatment is preferred due to the fact that adsorption is more efficient in stages.

As chlorine and carbon counteract one another some separation should be provided between their respective points of application. If carbon is applied first there should be a contact period of some 20 minutes prior to the application of chlorine.

It has been noted in some cases that chlorine tends to fix or stabilize tastes and odours in water. This is especially true at lower chlorine dosages, i.e., prior to the breakpoint. Therefore, in these cases, it would be advisable to apply the carbon ahead of the pre-chlorine. Where taste and odour treatment is necessary on a continuous basis, it will be necessary to consider the development of growths in the works upstream of the point of pre-chlorination.

For mild taste and odour problems, i.e. those requiring a carbon dosage of up to 10 ppm., the carbon can effectively applied to the top of the filter. This gives the most prompt improvement to the plant effluent. In addition, none of the effectiveness of the carbon is lost by adsorption into the existing sludge in the settling tanks. Also, the normal treatment of coagulation and settling is allowed to remove its share of the taste and odour producing material before applying the carbon. Carbon dosages at this level do not significantly reduce filter runs.

For pronounced taste and odour problems and where they occur frequently it is more desirable to apply the carbon at the mixing or coagulation basins. It is generally advisable to apply the carbon after the floc formation. This will help to prevent the alum from coating and lowering the adsorptive ability of the carbon particles. When carbon is applied at this point the upper dosage limit is increased measurably due to the large percentage removal in the settling basins. Dosages of up to 1200 ppm. have been reported with this point of application. It is also indicated that when carbon is applied at this point, coagulation is improved and the settled sludge becomes more stable.

FEEDING ACTIVATED CARBON

Activated carbon can be fed either dry or in slurry form. The two terms apply to the stage of measuring as the material in either case is wet mixed before its application to the water. One of the problems associated with the use of carbon in the past has been due to dust. This has been overcome for the most part by the development of equipment wherein the bag is opened inside a dust proof container. In dry feed equipment care must be taken to prevent arching of the carbon in the hopper. For slurry feed equipment consideration must be given to keeping the mixture in suspension prior to feeding.

The following is a suggested method for the emergency slurry feeding of carbon :-

> Install a small diameter pipe with a gate valve at the bottom of a 40-gallon drum and place near the point of application. The drum should be half filled with water and a bag of activated carbon carefully emptied into it. It is not advisable to shake the bag for removal of the last remnants as the amount obtained is not worth the dust problem. The mixture should be left for two or three hours in order to allow time for the carbon to wet. A wood

paddle can then be used for stirring the carbon into suspension. If available, a mechanical mixer can be employed. After the carbon is wetted and mixed, fill the remaining portion of the drum with water and stir into a uniform solution. The slurry can then be gravity fed to the water. It will require frequent stirring to keep the carbon in suspension. If more than 40 gallons of mixture is needed it will be necessary to start the preparation of a second drum some two hours prior to the emptying of the first. This is to allow for the wetting period.

CARBON DOSAGE

When a taste and odour problem occurs a common method of determining the correct dosage is to intermittently increase the carbon feed until a palatable water is obtained. In this method it is necessary to time the sampling periods to the correct flow through time in relation to the time of dosage adjustment.

The following is an illustration of this :-

- carbon applied at inlet to settling tanks
- settling tank capacity 80,000 gallons
- pumping rate 670 gallons per minute
- sampling point at effluent of filters
- carbon dosage adjusted at 10:00 a.m.
- settling tank flow through time = $\frac{80,000}{670}$ = 120 minutes
- allowance for filters etc. = 15 minutes
- Total = 135 minutes or 2 hours and 15 minutes

$\therefore$ Filtered water should be tested at 12:15 p.m. and carbon dosage adjusted.

Where the problem is severe it is generally better to overdose with carbon and slowly cut back the dosage until a palatable water is obtained.

The following is a more exact method of establishing the correct dosage :-

Obtain five 1-litre samples of the odour-bearing water from a point ahead of the carbon application. Make up a stock carbon solution by adding one gram of carbon to one litre of odour and taste free water. A millilitre of this stock solution in a litre of sample is equivalent to a carbon dosage of 1 ppm. Add varying amounts of the stock carbon solution to the water samples such as to produce dosages of 5, 10, 25 and 50 ppm. The fifth sample will serve as a blank. The samples are each agitated for 30 minutes, coagulated and filtered through glass wool. The filtrate is then tested and the lowest acceptable dosage determined. A more exact determination of the dosage can be obtained by plotting the carbon dosage against the threshold number as indicated on Fig.# 1. It is generally found that plant scale treatment is more efficient than the laboratory tests. As a rule it is only necessary to apply half the dosage determined in the laboratory tests. A compromise method to the above noted systems is as follows :-

Prepare a stock suspension by mixing a level teaspoon of carbon in a gallon of odour and taste free water. Add varying amounts (measured in teaspoons) of the stock solution to gallon samples of the contaminated water. As before five samples can be used. Filter the treated samples through a funnel filled with loosely packed absorbent cotton. The various filtrates can then be checked for palatability. The number of teaspoons of stock suspension added to the satisfactory sample is miltiplied by 1.8 in order to obtain the carbon dose in pounds per million gallons; or divided by 5.5 for carbon dosage in parts per million.

CARBON STORAGE

Stored activated carbon readily adsorbs vapours which will subsequently reduce its effectiveness in water treatment. For this reason the material should be stored in an area free from air contaminants such as gasoline vapours, chlorine and sulphur dioxide.

Activated carbon should be stored in a room free from sparks, machinery in operation, unprotected electric switches and wiring. "No Smoking" signs should be displayed in the storage area.

The bags should be stored off the ground and in rows so that adequate ventilation can be provided.

In case of fire, a chemical foam or a water mist spray should be used. Jets of water will serve to spread the particles and fire over a greater area.

GRANULAR CARBON FILTERS

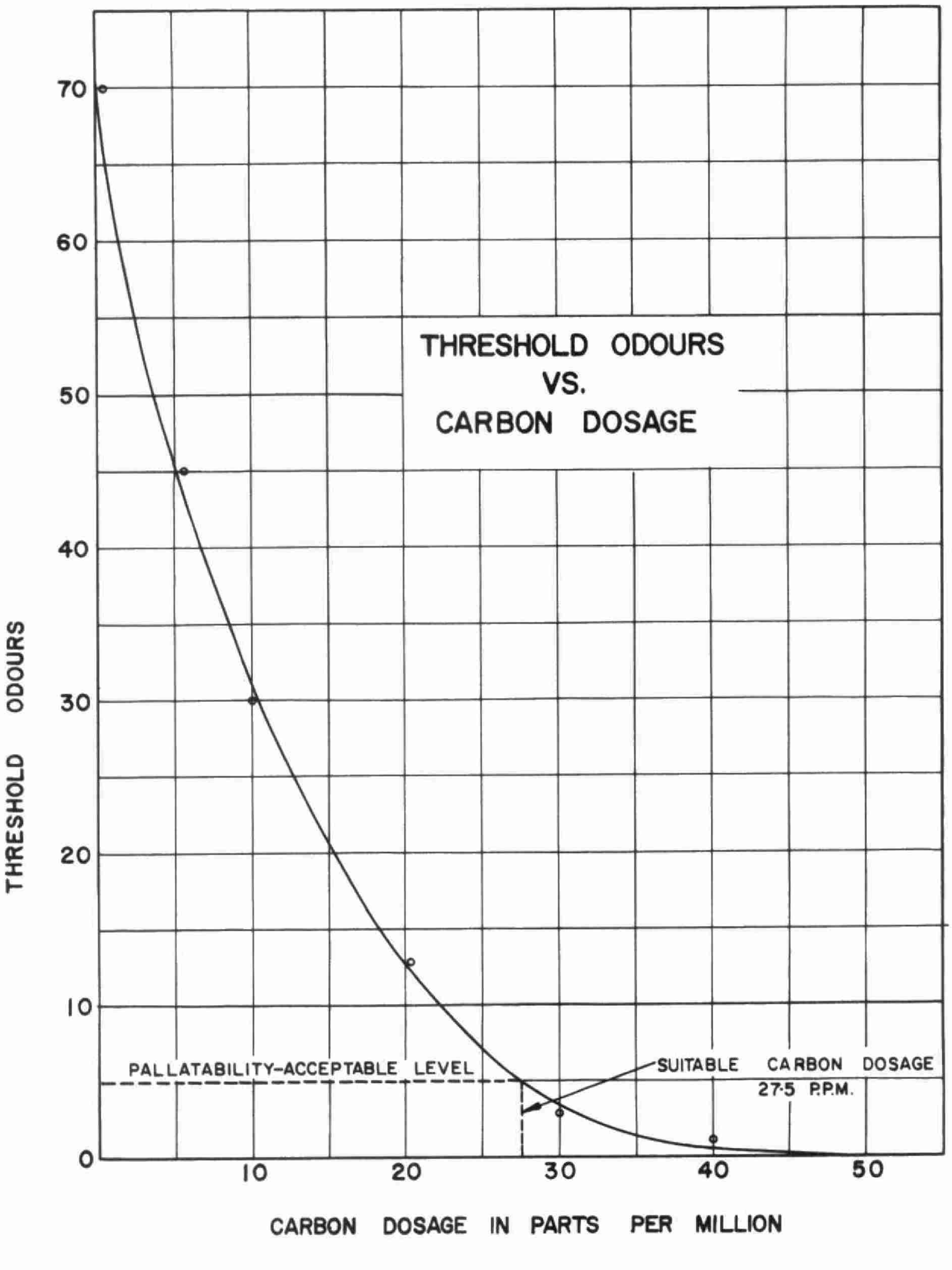
The use of granular, activated carbon filter beds has recently received more attention in the water works field. Such beds were utilized to a limited extent in the United Stated during the 1930's. However, due to limitations in the quality of the commercially available carbon of that era, this type of treatment met with limited acceptance. Today, such filters are relatively common in the municipal water works field in Europe and also for industrial use both in Europe and on this continent.

Such filters can be used in series with conventional sand and gravel filters or by themselves. In the former case they remove tastes and odours and organic material which passes through a conventional filter. In the latter case they perform the functions of both types of filters.

The most likely form of installation in this country would be where they follow a conventional filter. In these cases the beds would be similar to sand and gravel filters with a media depth of two to 10 feet. The media is removed at irregular periods, say three to 18 months and conveyed to a furnace where it is re-activated. The capital cost for a minimum size furnace to re-activate this is $50,000. For this reason the method is restricted more to the larger plants. The carbon can of course be replaced with virgin carbon at the end of its cycle. However, the cost of new carbon is in the order of 27¢ per pound, whereas it can be re-activated for a cost of 3¢ per pound. The time cycle for the carbon could be determined by the threshold odour test. That is the filter would be put out of service say when the threshold odour reach four. Filter rates in the order of two to 10 gpm per square foot are used.

In addition to removing tastes and odours such filters will remove many pesticides, viruses, detergents and other chemical pollutants. As some of these pollutants are not physically detectable at toxic limits, carbon granular filtration will provide an added degree of safety to a water supply. One problem which may be associated with these beds is the development of bacteria in the adsorbed material in the media. The intermittent use of a bacteriacide may be necessary. For this purpose chlorine has limitations due to the conflicting qualities of carbon and chlorine.

For an average size conventional filtration plant it costs 10¢ per 1,000 gallons to treat water (capital and operating costs included). To add granular activated carbon filters to such a plant would increase this cost by an average of 4¢ per 1,000 gallons.



NOTE: REQUIRED PLANT DOSAGE IS GENERALLY ONE HALF LABORATORY DOSAGE, OR IN THIS CASE 13·75 P.P.M.

CHLORINATION PART II

G. R. Trewin, Assistant Director

Division of Sanitary Engineering

INTRODUCTION

The first lecture on Chlorination reviewed four phases of the subject:

purpose of chlorination;
chlorine chemistry;
bacteriacidal effectiveness; and
chlorine residual determination.

This lecture will delve further into the subject under the following headings:

types of chlorine residual;
equipment;
routine operation;
emergency operation; and
adverse bacteriological results.

TYPES OF CHLORINE RESIDUAL

There are three specific types of chlorine residual which are used in the treatment of water. These are: combined and free residual chlorine and chlorine dioxide.

Combined Residual Chlorination

Combined residual chlorination is defined as the application of chlorine to water to produce, with natural or added ammonia, a combined available chlorine residual. A true combined available chlorine residual should contain little or no free available chlorine. A desirable combined residual is obtained with ammonia to chlorine ratios of 1:3 to 1:4. As the chlorine dosage is increased the ammonia will be oxidized. The break point, or complete destruction of ammonia will occur when the chlorine dosage is between 10 and 25 times that of the ammonia, either natural or added, concentration.

Available data show that, under most favourable conditions: (a) to obtain equivalent bactericidal action with the same period of exposure, about 25 times as much combined available residual chlorine as free available chlorine residual is required and (b) to obtain equivalent bactericidal action with the same amount of combined available chlorine residual as free available residual a contact period of approximately 100 times as long is required.

As indicated above, the ammonia may be present in the raw water in the natural state or it may be added artificially. This means that the combined residual may be an accident of nature, or on the other hand, an intended process to control taste and odour problems or maintain a residual over a period of time in the distribution system. A large portion of the surface supplies practice marginal chlorination on waters containing ammonia in excess of 0.05 m.g./liter. This means that by accident most of these systems maintain either a partial or complete combined chlorine residual in their disinfection program.

Free Residual Chlorination

Break Point Chlorination

Super Chlorination

Break point and super chlorination are both specific types of free residual chlorination programs. Free residual chlorination is defined as the application of chlorine to water to produce directly, or through the destruction of ammonia, a free available chlorine residual. The theoretical amount of chlorine required to arrive at the break point, when ammonia is present, has been variously reported to be 7.5 to 10 times the ammonia nitrogen content in the water. In practice, due to the presence of organic matter, possibly 10 to 25 times as much chlorine as ammonia nitrogen may be required to reach the break point. Super chlorination is a term used for a type of free residual program whereby a high chlorine residual is maintained to increase the rate of reaction between the chlorine and taste and odour causing chemicals. Because of the excess quantities of chlorine remaining in the water, after the required contact period, dechlorination is required before the water is distributed to the consumer. Break point chlorination is a type of free residual chlorination program whereby a minimum quantity of chlorine is used to obtain a free residual after the complete or near complete oxidation of

the ammonia is accomplished. A true break point program is very difficult to maintain because of varying raw water quality and the difficulties involved in oxidizing complex protein matter.

Because of the complexities of the process it is generally more satisfactory to accomplish a free residual chlorination program by the addition of an excess quantities of chlorine beyond the break point with excess chlorine being removed after an appropriate detention period. Dechlorination may be accomplished using sulphur dioxide or ammonia.

Chlorine Dioxide

A chlorine dioxide residual is obtained by the reaction of sodium chlorite and chlorine in a reaction tower. Experience has indicated that chlorine dioxide is effective in controlling chlorophenolic taste. It is suspected that this is accomplished because of the high oxidation potential of the chlorine dioxide whereby phenol may be completely oxidized without higher free residuals.

EQUIPMENT

Capacity of Equipment

Chlorinators should have a feed capacity of at least 50 percent greater than the highest expected dosage required to provide a free chlorine residual. In addition all chlorination equipment should be installed in duplicate so as to provide standby capacity for ensuring uninterrupted operation. When pre and post chlorination is practiced one standby unit would be sufficient to cover the two units in regular operation.

Chlorinators and Controls

Two types of chlorinators are available for dependable operation. The gas type chlorinator is most commonly used in large installations because of chemical cost economy. The second type of chlorinator available is a solution feeder which should be of the positive displacement type rather than a simple suction operated unit.

Automatic proportioning of the chlorine dosage should be provided for (a) all larger installations and (b) any installation where the flow rate varies without the manual adjustment of pumping rates.

Automatic equipment is now available to adjust both for varying flow rates and varying chlorine demands. This type of unit is very complex and should not be installed unless special maintenance staff is available.

Spare parts consisting of at least the commonly expendable items such as glassware, rubber fittings, hose clamps and gaskets should be provided for effecting emergency repairs. In addition consideration would be given to keeping a chlorinator capacity conversion kit to provide for a 100 percent increase in feed rate.

Weigh Scales

When a gas feed chlorinator is employed a set of corrosion resistant scales should be made available for weighing the chlorine cylinders serving each operating chlorinator.

Hypochlorite Feed Apparatus

When a powder product is used to make up hypochlorite solutions a separate preparation tank is required. The additional tank ensures that a clarified liquid is available for the hypochlorinator.

Safety Equipment

A self contained or air supplied type of respirator or mask should be available either at each chlorination installation or from a local fire department or other agency. When a cannister type mask is used in place of a self contained or air supplied unit instructions should be posted in a conspicuous place indicating that the mask should not be used for strong chlorine concentrations. In addition the face mask used with a cannister unit should be adjusted for the individual operator so as to provide air-tight operation in time of emergency. One respirator or air supply unit should be immediately available located in a conspicuous location outside the area of probable contamination.

Protective Clothing and Equipment

Deluge type safety shower, eye wash fountains, recess type scales, safety chains on upright chlorine cylinders are all items which require attention.

Building Detail

Gas chlorine equipment chlorinators, weigh scales, chlorine cylinders should be located in an isolated building, room or rooms. In larger installations the storage and scale facilities should be in a room separated from the chlorinators. In new installations it is suggested that all exit doors open to the outside to prevent the possible leakage of chlorine to other equipment areas. In addition the doors should be hinged to open outwardly.

Ton cylinders are stored separately on their sides on level racks between four and eight inches off the grade. Chlorine should not be stored below ground level and the cylinders must be protected from excessive heat, dampness, and mechanical damage. Continuous mechanical ventilation at a rate of three air changes every hour should be provided or screened openings to the outdoors located within six inches of the floor in the ratio of one square foot per 500 square feet of floor area. Similar openings should be provided in or near the ceiling. In addition, provision should be made for mechanical ventilation sufficient to produce 30 air changes per hour taking suction from the room at a maximum of three feet above the floor level.

The temperature in the storage and scale room should not be higher than the temperature in the chlorinator room. The gas lines between the scales, chlorinators, and injectors should not be located on an outside wall or in a location where low temperatures are encountered.

Testing Equipment

The minimum required testing equipment is a permanent standard chlorine residual comparator test kit. In addition it is recommended that more complex or larger chlorination programs be controlled using an amperometric titrator. This unit allows for the determination of the free and combined chlorine residuals.

In larger installations where poor raw water quality and/or minimum supervision indicates a hazard a chlorine residual recorder should be obtained. The recorder should be equipped with the low level residual alarm and installed to measure the chlorine residual in the water leaving the treatment plant.

ROUTINE OPERATION

Chlorine Residual

Figure 1 represents the minimum required chlorine residuals and retention periods as recommended from studies by Butterfield. In addition, appended as Item 3 are 100 percent kill curves for both free and combined chlorine residuals. The information provided in both figures deals entirely with bacterial control. Higher residuals are required to obtain a 100 percent kill for certain pathogenic viruses and parasites. From this information it is readily seen that few water supplies intentionally operate in the indicated chlorine residual ranges. This presents a need for careful sanitary control. Where pollution of the source of supply is possible, free residual chlorination should be practised.

As a minimum standard it is suggested that a 0.5 ppm chlorine residual be maintained in the water leaving the pumping station. When a free residual is assured and proven by continuous recording, and the source of supply is upstream from possible pollution sources, a 0.2 ppm chlorine residual may be considered as a minimum. At least 80 percent of the total chlorine residual should be in the free state before the process is considered to be a free residual chlorination program.

A minimum residual of 0.2 ppm in the water leaving the plant may be considered in instances where pre chlorination is effected and a contact period of at least two hours is assured after the application of chlorine.

Free residual chlorination should be the objective of all water supplies unless there is little likelihood of upstream contamination. In addition it is suggested that a chlorine residual be maintained in all active parts of the distribution system.

Chlorine Application Points

Where possible pre and post chlorination should be practised. The pre chlorination dose should be such as to maintain adequate chlorine residual levels throughout the plant.

The minimum contact time between the water and the chlorine before the first possible consumer should never be less than 15 minutes.

Chlorine Residual Test

The following procedure should be followed in performing the orthotolidine chlorine residual test.

1. Draw sample of chlorinated water. The tap should be kept running continuously or for a few minutes before taking the sample.

2. Allow sample to stand for 15 minutes to simulate the required minimum contact period.

3. Use 0.5 ml of orthotolidine (O.T.) reagent in 10 ml cells, 0.75 in 15 ml cells, and five ml in 100 ml tubes. Place reagent in testing tube; add sample to required volume; and mix. When the temperature of the sample is less than 68°F bring it to that temperature quickly after mixing with the O.T.

4. A colour comparison is made when the maximum colour develops.

5. The test results are recorded in the plant records and the necessary alteration is made to the chlorine application rate.

The above procedure is satisfactory for determining the total available chlorine residual. When the free residual is required the sample must be near 32°F when the O.T. is added and the colour comparison is made immediately. The orthotolidine-arsenite (O.T.) test can also be used to determine the free available chlorine residual.

The accuracy of a chlorine residual recorder should be checked daily. This is accomplished using either the amperometric titration or orthotolidine colourimetric test procedures. The results of the check are inscribed on the recording chart along with the date and operator's initials opposite a mark showing the time of the check.

The chlorine residual test must be performed frequently enough to ensure that an adequate chlorine residual is maintained at all times. Such points as raw water quality, chlorine demand, and changing flow rates must be taken into consideration. When a residual recorder alarm system is used the testing frequency may be reduced.

Records

Minimum records should include:

1. daily records of the chlorine used and weigh scale readings,
2. results from all chlorine residual tests,
3. the water flow rate and chlorine feed rate in both pounds per 24 hours and in ppm at the time of testing,
4. water used and chlorine dosage in ppm on a daily basis,
5. detail on chlorine cylinder changes, orders and chlorine on hand, and
6. monthly and yearly summaries of chlorine consumption and feed rates.

EMERGENCY OPERATION

Where chlorination is required for disinfection purposes a continuous feed of chlorine must be assured. For this type of service the operating authority should develop a standby operating procedure to cover emergencies. The procedures developed should be posted in a prominent location in the plant and all operators should be made aware of the information thus given.

The emergency information should include:

1. the order not to pump unchlorinated water to the distribution system,

2. the name, address and telephone number of -
   (a) senior supervisory personnel,
   (b) medical officer of health,
   (c) provincial or state regulatory authority,
   (d) chlorinator service company, and
   (e) chlorine supplier.

3. the order to notify immediately the state or provincial authority and the medical officer of health if unchlorinated water is directed to the distribution system,

4. details on emergency chlorination procedures, and

5. a statement on operator responsibility.

When emergency chlorination is provided the minimum chlorine residual in the water leaving the plant should be 1.0 ppm.

When unchlorinated water has been directed to the distribution system, and until direction is obtained from the provincial or state authority or medical officer of health the chlorine feed rate should be increased and a program of hydrant flushing initiated to provide a minimum chlorine residual of 1.0 ppm in the whole of the distribution system. When increasing the chlorine residual or carrying out an extensive hydrant flushing program, notify all customer that may be adversely affected.

ADVERSE BACTERIOLOGICAL RESULTS

When the results from the bacteriological sampling program do not meet the requirements of the provincial or state authority the medical officer of health and the regulatory authority should be notified. One or a number of the following procedures may be recommended to protect the supply:

(a) the disinfection, for a 24-hour period, of the distribution system with a solution having a starting strength of 50 ppm of available chlorine;

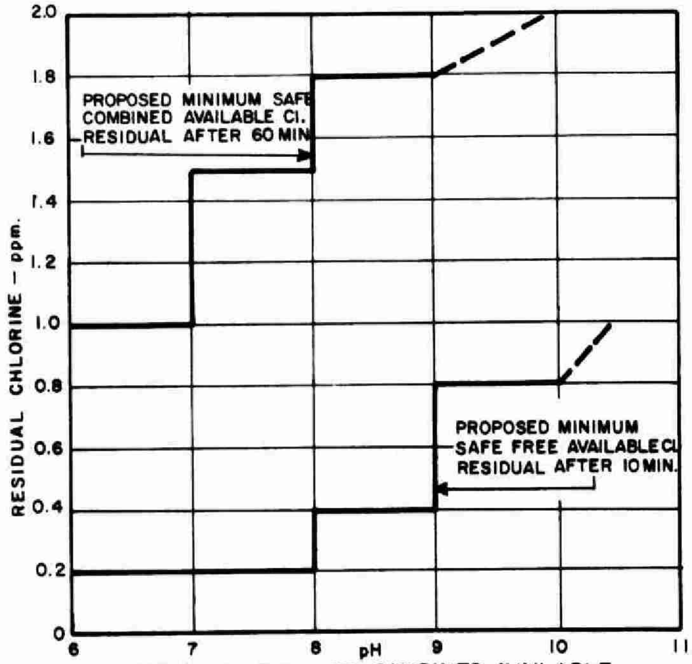
(b) the initiation of chlorination procedures on an unchlorinated supply;

(c) an increased chlorine residual requirement along with a distribution system flushing program;

(d) the collection of further samples;

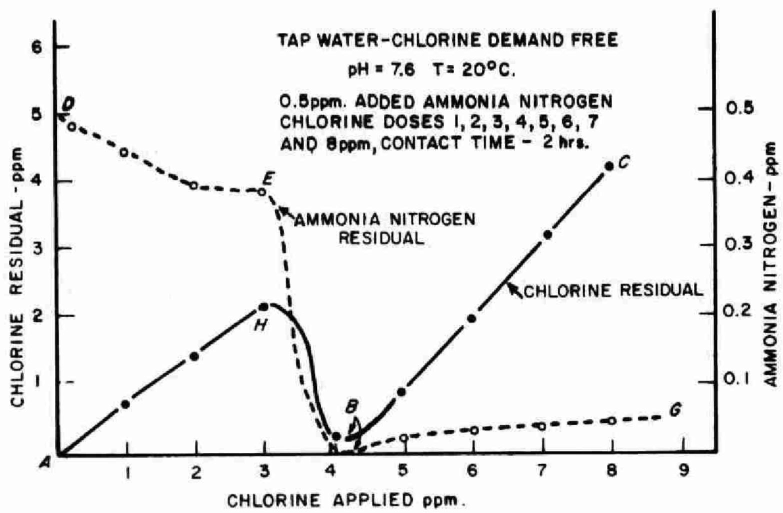
(e) a recommendation to the medical officer of health that a boil water order be issued.

FIG. 1



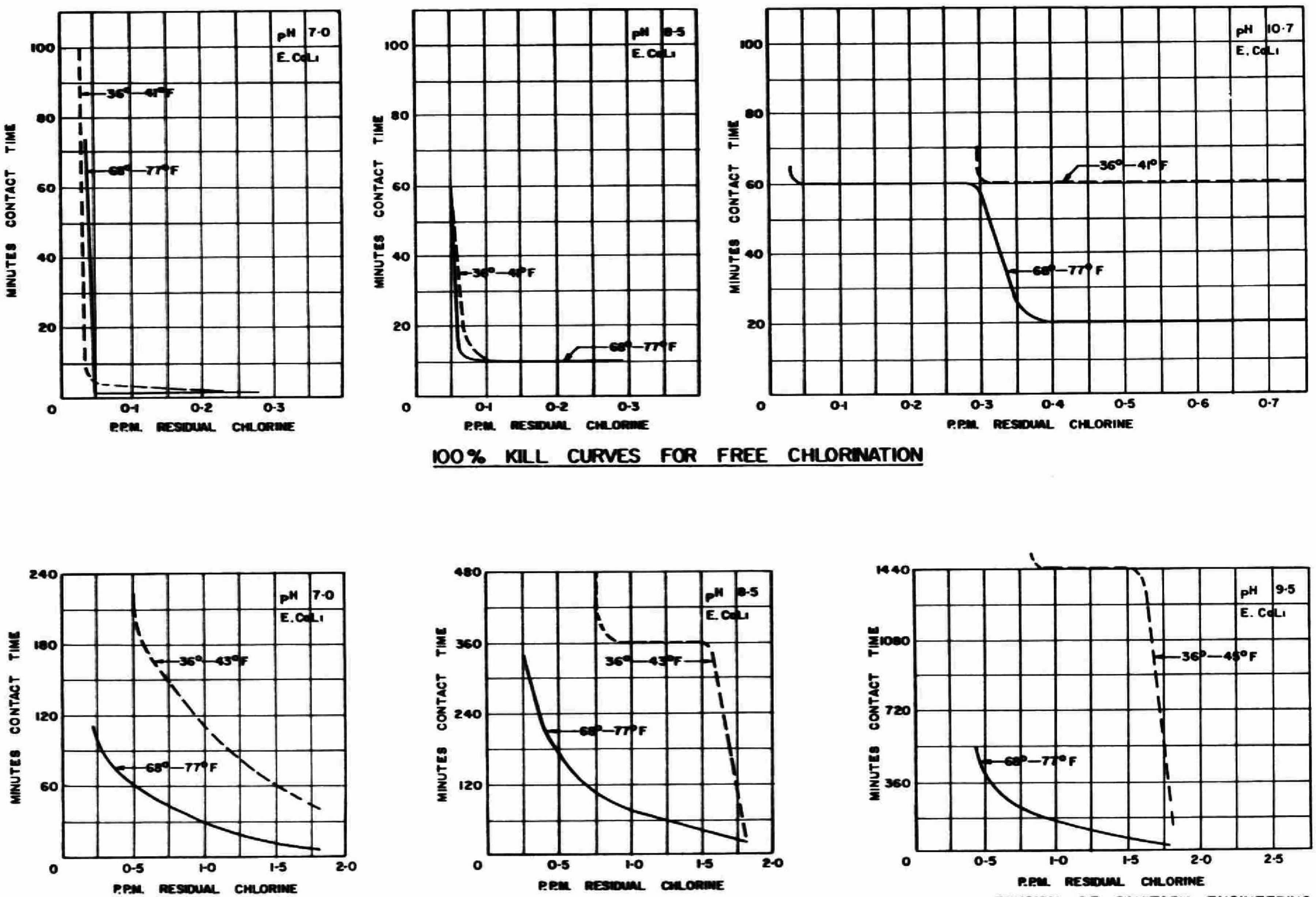
MINIMUM FREE OR COMBINED AVAILABLE CHLORINE RESIDUALS BY BUTTERFIELD. U.S. PUBLIC HEALTH EXPERIMENTS

FIG. 2



THE BREAK-POINT PROCESS

100% KILL CURVES FOR CHLORINATION



100% KILL CURVES FOR COMBINED CHLORINATION

DIVISION OF SANITARY ENGINEERING
ILLINOIS DEPARTMENT OF PUBLIC HEALTH T.R. 10–2
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FIGURE 3

DISTRIBUTION SYSTEM HYDRAULICS

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INTRODUCTION

The subjects to be discussed at the Intermediate Water Works Operators Course are: 1) flow of water under pressure in closed pipes; 2) calculating actual system residual pressures; and 3) conducting pressure and flow tests on the distribution system.

These subjects follow from the basic course which covers fluid properties, fluid pressure, absolute and gauge pressures. Water treatment plant and filter hydraulics will be included in the senior course.

The emphasis is upon practical application. Comprehension of the basic principles is not required so long as the operator is able to solve the practical problems using the tools and methods provided.

FLOW OF WATER UNDER PRESSURE IN CLOSED PIPES

To solve flow problems in closed pipes, it is necessary to use the equation of continuity which is based on the conservation of mass; the energy balance equation which is based on the conservation of energy; and an energy loss formula for flow in pipes.

Equation of Continuity (Figure 1)

If the cross-sectional areas and average velocities at sections one and two of Figure 1 in the pipe are designated by A1, A2, V_1 and V_2 respectively, the quanitity of fluid passing section one per unit of time will be expressed by A_1, V_1, and the quantity of fluid passing section two per unit of time will be expressed by A_2, V_2.

That is, at section one Q_1 is equal to A1, V_1 and at section two Q_2 is equal to A_2, V_2

Since no fluid mass is being created or destroyed

$$Q_1 = Q_2 \text{ and}$$
$$A_1, V_1 = A_2, V_2$$

The product Q is designated as the rate of flow and has dimensions of cubic feet per second (cfs). The rate of flow or discharge is the volume of water passing a given point in a specified time. It may also be expressed as gallons per minute or gallons per day.

Velocity is the rate at which water is moving. It may be expressed as feet per second (ft./sec.) or feet per minute (ft./min.).

Example:

Six hundred pounds of water flow per second through a pipeline consisting of 12-inch and 8-inch pipe. Calculate the flow rate in cubic feet per second and gallons per minute. Also, calculate the average velocities in the 12-inch and 8-inch sections.

$$Q = \frac{600}{62.4} = 9.61 \text{ cfs}$$

$$Q = 9.61 \text{ ft.}^3\text{/sec.} \times 6.24 \frac{\text{gal}}{\text{ft}^3} \times 60 \text{ sec./min.}$$

$$= 3590 \text{ gal./min.}$$

$$V_{12} = \frac{Q}{A} = \frac{9.61}{\pi/4 \quad \frac{(12)^2}{(12)^2}} = 12.23 \text{ ft./sec.}$$

where $A = \frac{\pi d^2}{4}$ and $\pi = 3.14$

$$V_8 = \frac{9.61}{\pi/4 \quad \frac{(8)^2}{(12)^2}} = 27.55 \text{ ft./sec.}$$

also $V_8 = Q \frac{(d12)^2}{(d8)^2} = 12.23 \times \frac{(12)^2}{(8)^2} = 27.55 \text{ ft./sec.}$

Energy Balance Equation (Figure 2)

Based on the law of conservation of energy, the total energy of a given system can neither be created nor destroyed. This means that the total energy at one point in a system is the same as at another point in the system. The several forms of energy may change, however, from one point to another in the same system.

For our purposes we will consider only:

1) Pressure energy 2) Kinetic energy
3) Potential energy 4) Heat energy

It is convenient to express the energy in terms of energy existing in or supplied to a single pound of water. Thus, the energies are expressed in foot-pounds per pound (ft.-lb./lb.) of fluid flowing.

Pressure Energy:

Pressure energy or pressure head (H) has previously been expressed in the basic course as equal to P/W foot-pounds per pound (ft.-lb./lb.)

Kinetic Energy:

The kinetic energy of a body is that energy stored in it by virtue of its weight and velocity. It is given by the formula $\frac{WV^2}{2g}$ foot-pounds (ft.-lb.). Here W = 1 and kinetic energy = $\frac{V^2}{2g}$ foot-pounds per pound (ft.-lb./lb.).

The term $\frac{V^2}{2g}$ is known as the velocity head. It was defined by Pitot's experiments in 1732. His experiments showed that when a small tube with open end facing upstream was placed in a flow where the velocity was V_0 that the liquid in the tube rose above the free surface in the piezometer column a distance $\frac{V_0^2}{2g}$.

Potential Energy:

The potential energy of a body is that energy stored in it by virtue of its weight and elevation above a datum plane. Here the potential energy of a pound of fluid Z feet above the datum plane is Z foot-pounds per pound (ft.-lb./lb.)

Heat Energy:

Flow of a real fluid such as water is complicated by the existence of viscosity. Viscosity introduces resistence to motion by causing shear or friction forces to exist between fluid particles and between these and boundary walls. For flow to take place, work must be done against these resistance forces and in the process, energy is converted into heat.

The total energy loss or head loss in a system is usually designated by H_L. The total energy loss (H_L) is the sum of friction losses (h_f) and minor losses (h_m). Determination of friction losses (h_f) will be discussed in the next section.

Minor losses may be determined from the formula $h_m = K \frac{V^2}{2g}$ Some values of K are given in Table 1.

Minor losses include those due to entrances, enlargements, contractions, exits, bends, valves and obstructions. For pipelines longer than 500 diameters, minor losses are usually neglected.

Figure 2 shows a section one and a section two through a pipe. Since energy is neither created nor destroyed in the flow system, the total energy at section one must equal the total energy at section two. This may be expressed in the form of an equation as follows:

$$\frac{P_1}{W} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{W} + V_2^2 + Z_2 + H_L$$

The sum of the potential and pressure energies is known as the hydraulic grade line. The hydraulic grade line gives a picture of the pressure variation in the flow. When the total energy remains unchanged and the velocity increases, then the sum of pressure and potential head must decrease. Where the potential head varies little, the approximate statement can be made that when velocity is high, pressure is low.

The sum of all energies is known as the energy grade line. The energy grade line always flows downward in the direction of flow. The hydraulic grade line, however, can slope upward in those zones of deceleration where velocity head is being converted to pressure head at a rate greater than the rate of loss.

The slope of the hydraulics grade line is called the hydraulic gradient. The slope of the energy grade line is called the energy gradient. These two gradients are the same, that is, parallel, where the velocity is not changing from section to section.

Energy Loss Formulas For Pipes (Figure 3)

A number of emperical formulas have been developed to determine energy loss due to friction in pipes.

One of the earliest expressions for energy loss in a pipe was developed by Chezy in 1775.

$$V = C\sqrt{RS}$$

where C = Chezy co-efficient

R = hydraulic radius = area of flow cross-section divided by the wetted perimeter

for a circular pipe diameter d, flowing full

$$R = \frac{\Pi d^2}{4 \times \Pi d} = d/4$$

$S = h_f/L$ = energy loss per foot of pipe = slope of the energy grade line

Of all the formulas which have been used to determine energy losses in pipes, only the Darcy Weisbach formula (1857), permits the proper evaluation of all factors which affect the loss. These are velocity, roughness, density, viscosity and dimensions of the conduit. The formula is $h_f = f \frac{L}{d} \frac{V^2}{2g}$. The term "f" called the "friction factor" can be determined from a special graph prepared by Moody (1944) from experimental results.

The Manning formula presented in 1890 is usually used for open channel flow problems.

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

where n = co-efficient of roughness

The expression 1.486/n was designed to make values of "n" correspond to the values of "n" in Kutter's formula which was presented in 1869.

For pipe used in the water works field "n" may vary from .010 to .015 depending on type and condition.

The Hazen-Williams formula (1905) is probably the most widely used in American practice for pipes flowing completely full.

$$V = 1.318\ C_{hw}\ R^{0.63}\ S^{0.54}$$

The constant C_{hw} commonly designated as C, may vary from 140 for clean, extremely smooth straight pipe to 60 for old cast-iron pipe in bad condition. This formula appears cumbersome with its fractional exponents. Fortunately, tables and charts have been prepared for solving every day problems. A typical alignment chart, Figure 3, is included with these notes.

CALCULATING RESIDUAL PRESSURES (Figure 4)

The first problem is to determine the residual pressure at the hydrant in the system shown in Figure 4, when the flow is 500 gpm taking into account all minor losses.

The second problem is to determine what the residual pressure would be if the last 1000 feet of pipe on the distribution system were 4-inch diameter rather than 6-inch diameter.

Problem One:

The problem is to determine the residual pressure at the hydrant in the system shown in Figure 4 when the flow is 500 gpm.

8-inch pipe:
With Q = 500 gpm, V = 3.6 fps and $V^2/2g = 0.20$ ft

1) Minor loss due to entrance $= K\ V^2/2g$ From Table 1 K = 0.5
$= 0.5 \times 0.20$
$= \underline{0.10 \text{ ft}}$

2) Friction loss in 50 feet of 8-inch pipe from Hazen-Williams chart using C = 100
$= \frac{10\ (\text{ft})}{1000\ (\text{ft})} \times 50\ (\text{ft}) = 0.5\ (\text{ft})$

3) Minor loss due to 90 degree medium sweep vertical bend = $K\ V^2/2g$

$= 0.6 \times 0.20$ From Table 1, $K = 0.6$

$= \underline{0.12 \text{ ft}}$

4) Friction Loss in 1000 feet of 8-inch pipe = $\underline{10.0 \text{ ft}}$

5) Minor loss due to expansion to 12-inch pipe

$= K\ V_8{}^2/2g$ $d/D = 8/12 = 2/3$

$= 0.33 \times 0.20$ From Table 1, $K = 0.33$

$= \underline{0.66 \text{ ft}}$

<u>12-inch pipe</u>:

With $Q = 500$ gpm, $V = 1.7$ fps and $\dfrac{V^2}{2g} = .045$ ft

6) Friction loss in 1000 feet of 12-inch pipe from Hazen=Williams chart using $C = 100$

$$= \frac{1.6\ (\text{ft})}{1000\ (\text{ft})} \times 1000 \text{ ft}$$

$$= \underline{1.6 \text{ ft.}}$$

<u>6-inch pipe</u>:

With $Q = 500$ gpm, $V = 6.5$ fps and $V^2/2g = 0.66$ ft

7) Minor loss due to contraction to 6-inch pipe

$= K\ V_6{}^2/2g$ $d/D = \dfrac{6}{12} = 0.5$

$= 0.33 \times 0.66$

$= \underline{0.22 \text{ ft}}$ From Table 1, $K = 0.33$

8) Friction loss in 500 feet of 6-inch pipe from Hazen-Williams chart using $C = 100$

$$= \frac{42\ (\text{ft})}{1500(\text{ft})} \times 500 \text{ ft}$$

$$= \underline{21 \text{ ft}}$$

9) Minor loss due to 6-inch gate valve 3/4 open

$= K\ V^2/2g$

$= 1.15 \times 0.66$ From Table 1, $K = 1.15$

$= \underline{0.75 \text{ ft}}$

10) Friction loss in 1000 feet of 6-inch pipe = $\underline{42.0 \text{ ft}}$

11) Minor loss due to exit in 6-inch pipe

$= K\ V^2/2g$

$= 1.0 \times 0.66$ From Table 1, $K = 1.0$

$= \underline{0.66 \text{ ft.}}$

The total head loss of the eleven items is 77.61 ft.

The water level in the elevated tank above the datum plane at the hydrant is 123.81 ft.

The residual pressure at the hydrant is

$$123.81 - 77.61 = 46.2 \text{ ft. or } 46.2 \text{ (ft)} \times \frac{\text{(psi)}}{2.31 \text{ (ft)}}$$

$$= 20 \text{ psi}$$

The difference between the energy grade line and the hydraulic grade line as shown in Figure 4 is very slight. As indicated previously, it is customary to neglect minor losses in those systems where the pipelines are longer than 500 diameters.

Problem Two:

Problem one was set-up to give the minimum recommended hydrant pressure of 20 lbs./sq. inch. If the last 1000 feet of the system were 4-inch diameter, the velocity would be 15.5 ft./sec., the velocity head $\left(\frac{V^2}{2g}\right)$ 3.7 ft., and the friction loss per 1000 feet still using C = 100, 340 (ft).

The total head loss for this 1000 foot section would then be:

$$340 \text{ ft.} \times \frac{1000 \text{ (ft)}}{1000 \text{ (ft)}} + 1.0 \times 3.7 \text{ (ft)} = 343.7 \text{ ft.}$$

The total head available in the system at the elevated tank is only 123.81 ft. Since the head loss in the last 4-inch diameter section greatly exceeds this, the system cannot deliver 500 gpm at the hydrant.

Example two has been included to demonstrate the severe loss of head which occurs when attempting to pass fire flows through 4-inch diameter pipe. You may be aware that the OWRC does not approve of the use of 4-inch diameter pipe in distribution systems for the purpose of providing fire flows. Four-inch diameter may be used, however, for looping and on short cul-de-sacs where fire protection is provided from larger mains.

PRESSURE AND FLOW TESTS (Figure 5)

A method used by the National Board of Fire Underwriters and adopted by the Canadian Underwriters Association is of value in determining head losses in distribution systems resulting from fire demands. It is also useful in determining weak points in the distribution system. The test consists of determining the pressure drop at a fire hydrant for a measured flow from a nearby hydrant or hydrants and using a ratio to determine the head loss for other flows.

Equipment Required (Figures 6, 7, and 8)

The equipment required includes a cap to cover the 2.5 inch outlet of the hydrant at which the pressure is to be read. Into the cap is tapped a ¼ inch copper pipe which has a T-connection for a 100 psi pressure gauge. At the end of the pipe is a cock to allow air to escape. There is also a stop cock on the line to the gauge. This equipment is shown in Figure 7.

A Pitot tube with air chamber and pressure gauge is necessary for checking the velocity pressure of the water at the nozzle. A Pitot tube may be of several suitable types. The type shown in Figure 6 & 8 may be readily constructed. It should be connected by brass or other non-ferrous metal pipe fittings to an air chamber and pressure gauge as shown. The Pitot tube should be kept free of dirt and the air chamber free of water. The gauge should read to 50 psi in 1/2 graduations. The assembly is obtainable from manufacturers of Pitot equipment.

Method

When a test is made, one or more hydrants are chosen for measuring discharge and one is chosen for reading pressure. If several hydrants are opened for flow, they are grouped about the one observed for pressure as for hydrant R in Figure 5. If a dead end line is being tested, the end hydrant should be the residual hydrant and the next nearest would be the opened one.

The test is begun by opening the air escape cock of the pressure gauge at the residual hydrant and then opening the hydrant valve. After the air has escaped, the cock is closed and the pressure is read. If the needle fluctuates, the centre point is read.

Then at a signal, one hydrant is opened and both the residual and Pitot pressures are read. At a signal, the next hydrant is opened and readings are made, and so on, until all hydrants to be opened are flowing. Then the hydrants are closed, slowly to prevent waterhammer, and the final pressure at the residual hydrant should return to the pressure before the test was started.

If the tests are to be significant, the following precautions should be observed:

1) The hydrants tested should form a group such as might be called into play in fighting a fire in the area under study;

2) Water should be drawn at a sufficient rate to create a drop in pressure greater than that caused by normal fluctuations in draft within the system. There should be sufficient flow to insure a pressure drop of at least 10 psi and also not so much that the residual will be reduced to 20 psi.

3) The time of the test should coincide with normal draft periods in the remainder of the system.

<u>Formulas</u> (Table 2)

The hydrant discharge rate Q_H (gpm) can be found in appropriate tables such as (Table 2) or can be computed from the formula $Q_H = 22.5\ d^2 \times \sqrt{p}$.

This formula is derived from the general nozzle flow formula as follows:

$$Q = C\,A\,\sqrt{2\ \frac{gP}{W}}$$

where $Q = \frac{Q_H}{376} \times \frac{(\text{gpm})}{(\text{gpm})/(\text{cfs})}$

A = area of nozzle = square feet

$$= \frac{\pi\ d^2}{4 \times 144} \quad (\text{ft}^2)$$

P = pressure = pounds per square ft
= $144\ p$ (lbs/ft^2)

C = nozzle co-efficient = 0.9

Substituting in the formula for small p (Pitot pressure reading in psi) and d (the diameter of the hydrant nozzle in inches

$$Q_H = 376 \times 0.9 \times \frac{3.14}{4} \times \frac{d^2}{144} \sqrt{\frac{32.2 \times 144 \times p}{62.4}}$$

$$= 1.85 \times d^2 \times 12.1 \sqrt{p}$$

$$= 22.5\, d^2 \sqrt{p} \quad \text{gpm}$$

The Canadian Underwriters Association generally prescribes that there should be a residual pressure of 20 psi. It is necessary to adjust the actual readings to determine flow which would occur with a residual of 20 psi in a nearby hydrant. This is done using the formula:

$$Q_A = Q_T \frac{h_A^{0.54}}{h_T^{0.54}}$$

in which Q_A is the flow available with a residual of 20 psi, Q_T is the test flow, h_A is the pressure drop available, and h_T is the pressure drop during the test.

It is sufficiently accurate to write this equation as $Q_A = Q_T \sqrt{\frac{h_A}{h_T}}$

Example:

For example, in Figure 5, if the hydrant nozzles are 2.5 inches inside diameter, the following table represents a typical test where the pressure has been observed with a pressure gauge at hydrant R before and after the test, and outlet pressures have been measured by the Pitot gauge at hydrants 1 to 4 inclusing.

Conditions	Observed Pressure at HYD R (psi)	Observed Velocity Pressure (psi)	Calculated Flow From Formula (gpm)
All hydrants closed	74	-	-
HYD 1 open	-	13.2	510
HYD 2 open	-	9.6	435
HYD 3 open	-	16.8	575
HYD 4 open	-	14.5	535
All hydrants open	46	-	-
All hydrants closed	74	-	-
		Total	2055

The simultaneous flow readings of all four hydrants produced a total flow of 2055 gpm. At this flow, the residual pressure at Hydrant R dropped 74-46 = 28 psi. The adjusted flow with a residual of 20 psi is therefore:

$$Q_A = 2055 \sqrt{\frac{74-20}{74-46}} = 2850 \text{ gpm}$$

DISTRIBUTION SYSTEM HYDRAULICS

INTERMEDIATE WATER WORKS OPERATORS COURSE

TABLE 1

MINOR LOSSES-$h_m = K\ V^2/2g$

Nature of Special Resistance	K
Entrance Losses-end of pipe flush with tank	0.5
Outlet Losses - from pipe into still water or atmosphere	1.0
Sudden Contraction -d/D = 1/4	0.42
d/D = 1/2	0.33
d/D = 3/4	0.19
Sudden Enlargement d/D = 1/4	0.92
d/D = 1/2	0.56
d/D = 3/4	0.19
Tee - Standard (full size branch)	1.5
90° bend - 0.0 radius	1.0 - 1.4
0.50 radius	0.3
medium sweep	0.6
Gate Valve - wide open	0.19
3/4 open	1.15
1/4 open	24.0
Globe Valve - wide open	10.0
Butterfly Valve $\emptyset = 10^{\circ}$	0.46
$\emptyset = 40^{\circ}$	10.0
$\emptyset = 70^{\circ}$	320.0
Check Valve - horizontal lift type	8.0 - 12.0
ball type	65.0 - 70.0
swing check	0.6 - 2.3
Plug valve - fully open	0.77
70% open	28.0

DISTRIBUTION SYSTEM HYDRAULICS

INTERMEDIATE WATER WORKS OPERATORS COURSE

TABLE 2

DISCHARGE TABLE FOR CIRCULAR OUTLETS

Outlet Pressure Measured by Pitot Gauge

Outlet pressure psi	Outlet Diameter 2½ in.	Outlet Pressure psi	Outlet Diameter 2½ in.
1	140	32	792
2	198	33	804
3	242	34	816
4	280	35	828
5	313	36	840
6	343	37	852
7	370	38	863
8	396	39	874
9	420	40	886
10	442	41	896
11	464	42	907
12	485	43	918
13	505	44	929
14	524	45	939
15	542	46	949
16	560	47	960
17	577	48	970
18	594	49	980
19	610	50	990
20	626	52	1009
21	642	54	1029
22	657	56	1047
23	671	58	1066
24	686	60	1084
25	700	62	1102
26	714	64	1120
27	727	66	1137
28	741	68	1154
29	754	70	1171
30	767	72	1188
31	779	74	1204

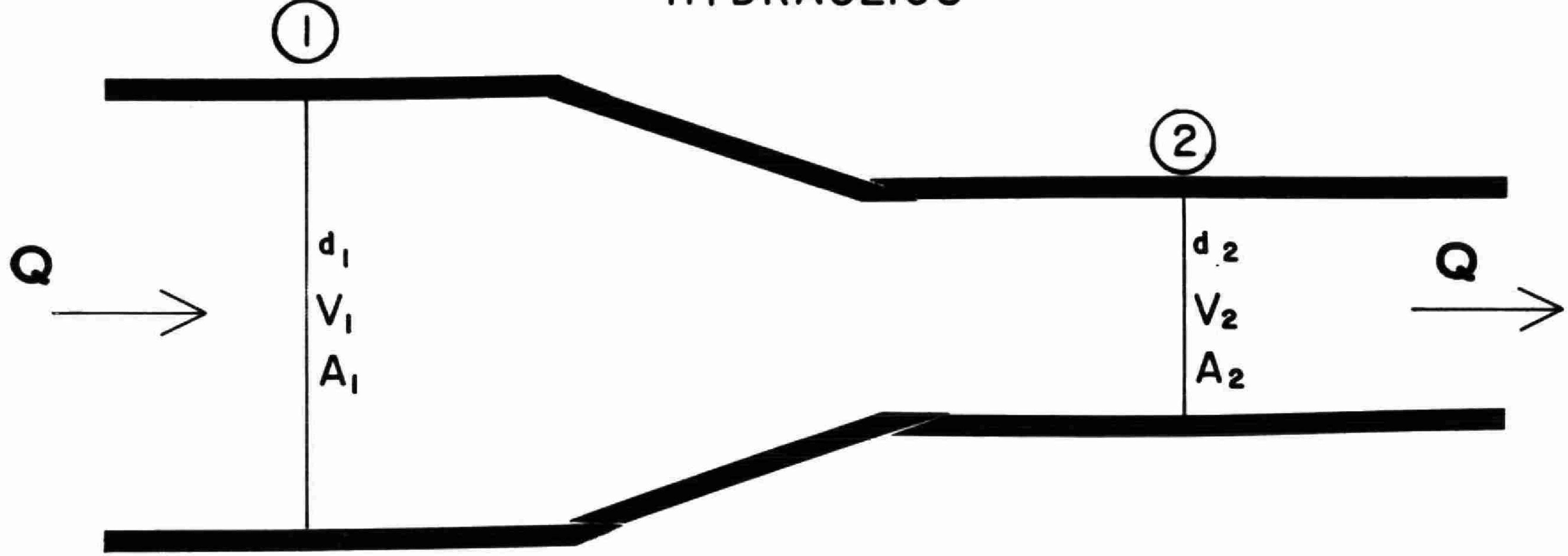
Orifice co-efficient C = 0.9

FIGURE I

CONTINUITY PRINCIPLE

INTERMEDIATE WATER WORKS OPERATORS COURSE

HYDRAULICS



$$Q = A_1 V_1 = A_2 V_2$$

$$V_2 = \frac{A_1 V_1}{A_2}$$

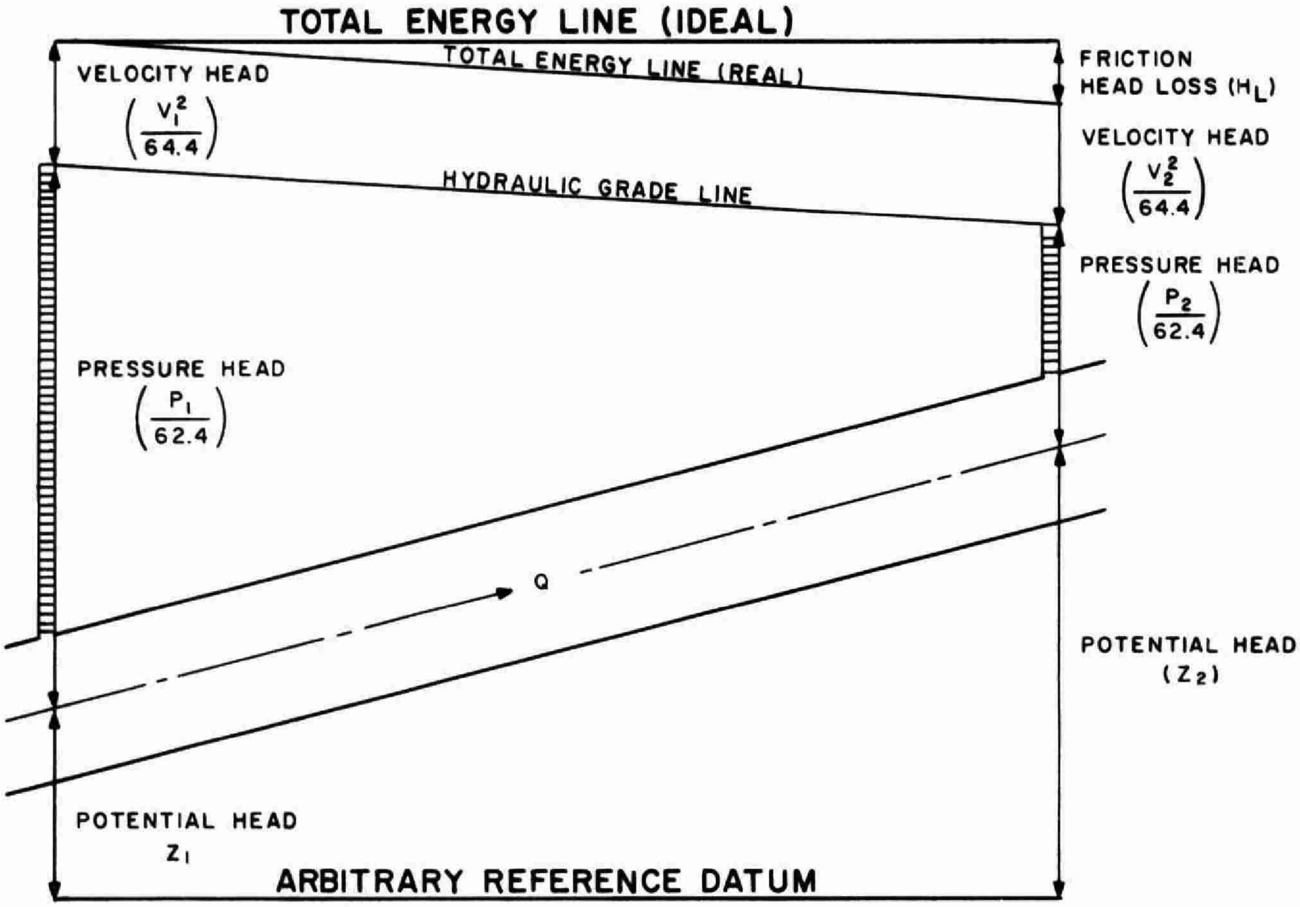
HYDRAULICS

INTERMEDIATE WATER WORKS OPERATORS COURSE

FIGURE 2

ENERGY RELATIONSHIPS FOR FLOW IN PIPES

(BERNOULLI PRINCIPLE)



(POTENTIAL HEAD)$_1$ + (PRESSURE HEAD)$_1$ + (VELOCITY HEAD)$_1$ =

(POTENTIAL HEAD)$_2$ + (PRESSURE HEAD)$_2$ + (VELOCITY HEAD)$_2$ + FRICTION HEAD LOSS.

INTERMEDIATE WATER WORKS OPERATORS COURSE
DISTRIBUTION SYSTEM HYDRALICS

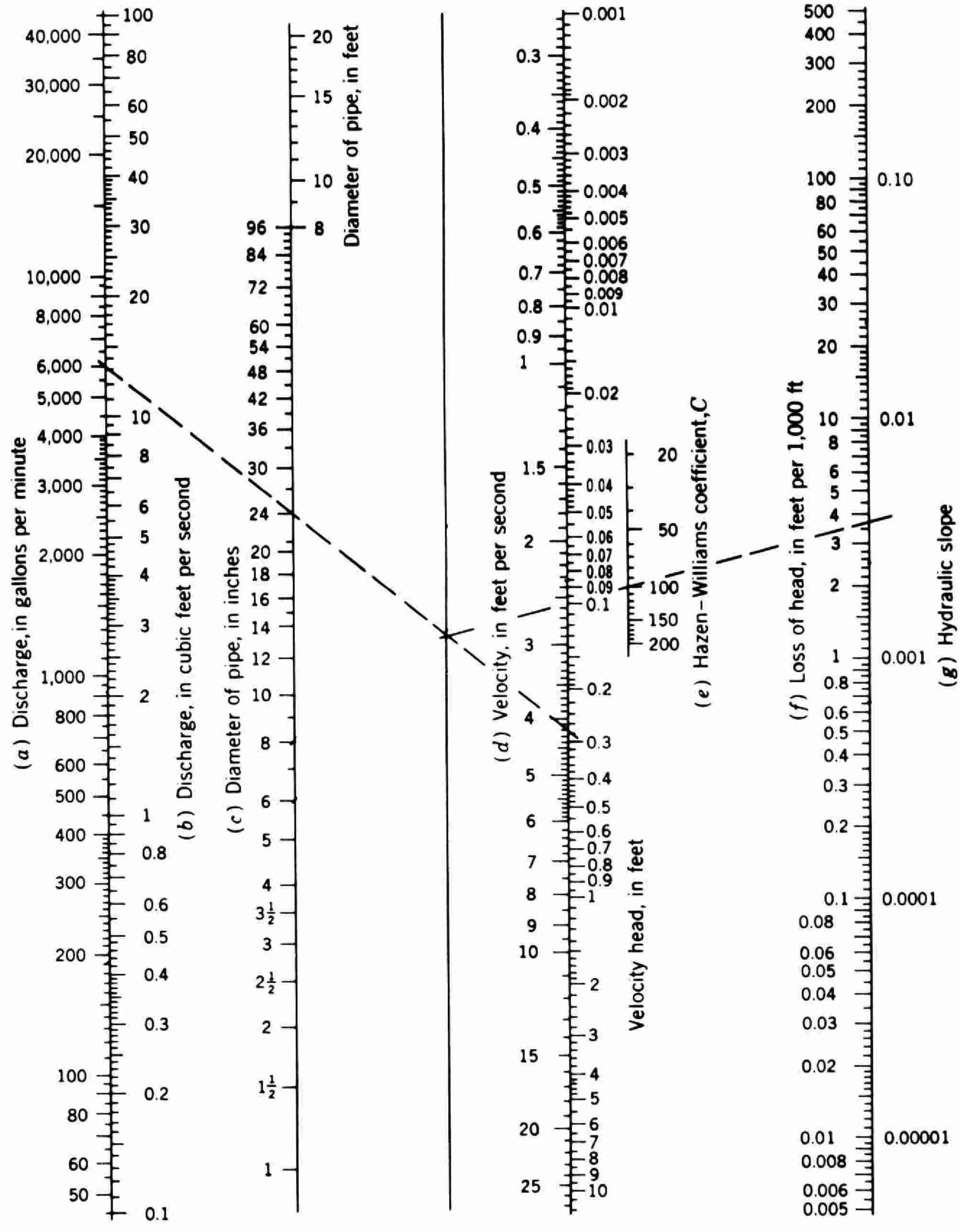


FIG. 3 .—ALIGNMENT CHART FOR FLOW IN PIPES (HAZEN-WILLIAMS FORMULA)

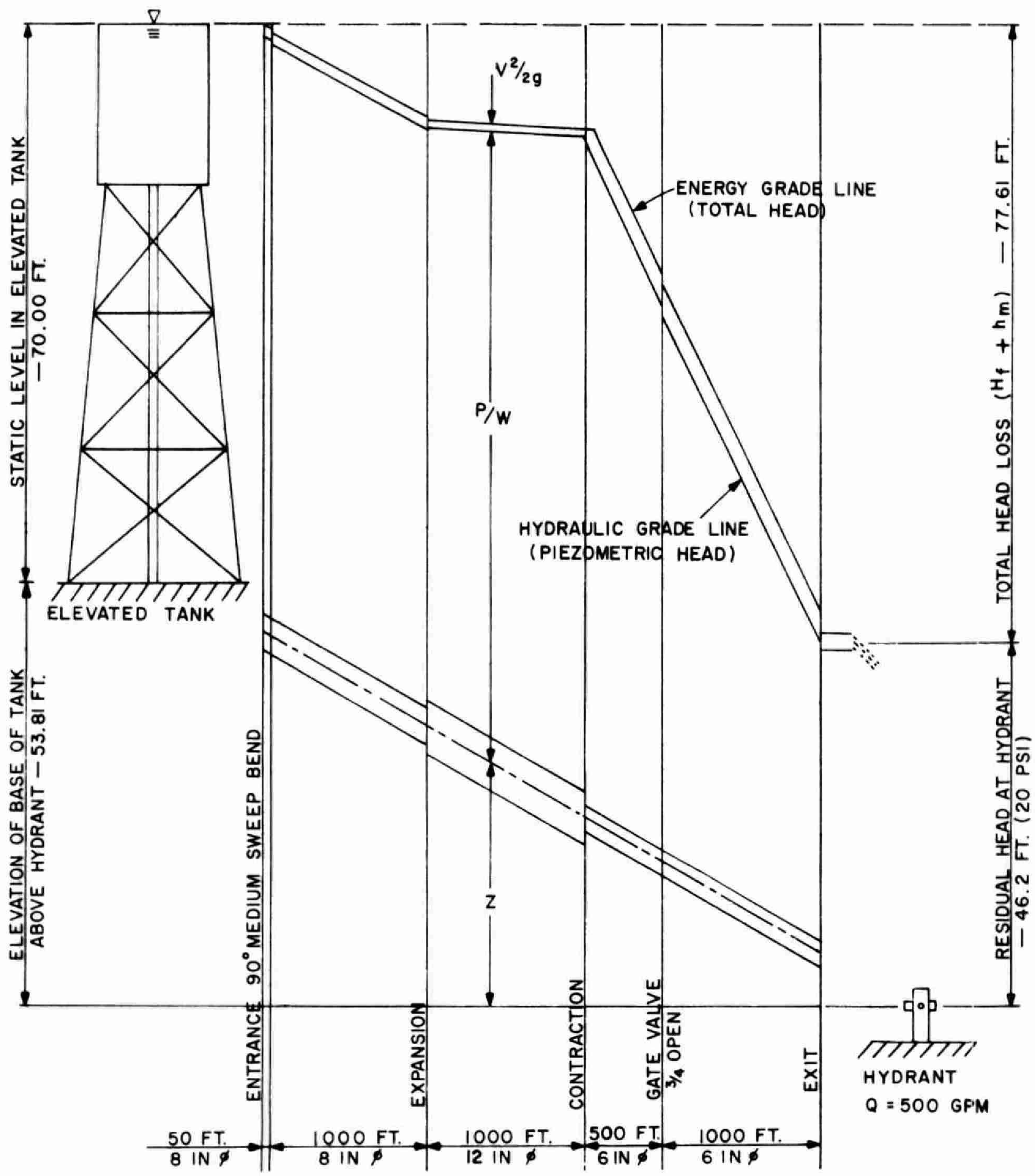

$V^2/2g$
ENERGY GRADE LINE
(TOTAL HEAD)
P/W
HYDRAULIC GRADE LINE
(PIEZOMETRIC HEAD)
Z
STATIC LEVEL IN ELEVATED TANK
— 70.00 FT.
ELEVATED TANK
ELEVATION OF BASE OF TANK
ABOVE HYDRANT — 53.81 FT.
TOTAL HEAD LOSS ($H_f + h_m$) — 77.61 FT.
RESIDUAL HEAD AT HYDRANT
— 46.2 FT. (20 PSI)
ENTRANCE 90° MEDIUM SWEEP BEND
EXPANSION
CONTRACTION
GATE VALVE
3/4 OPEN
EXIT
HYDRANT
Q = 500 GPM
50 FT.
8 IN ø
1000 FT.
8 IN ø
1000 FT.
12 IN ø
500 FT.
6 IN ø
1000 FT.
6 IN ø

FIG. 4

INTERMEDIATE WATER WORKS OPERATORS COURSE

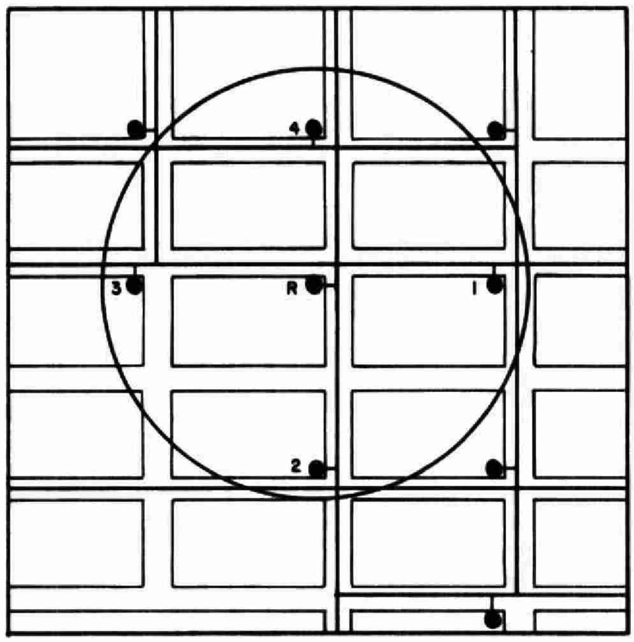
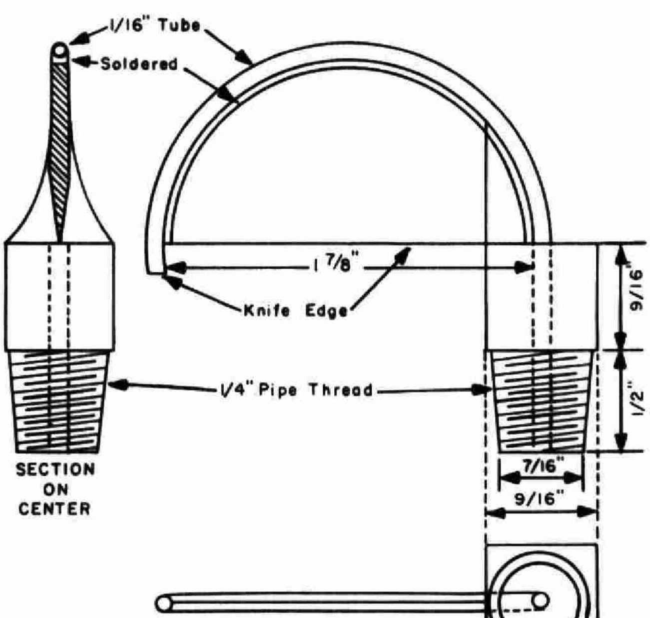
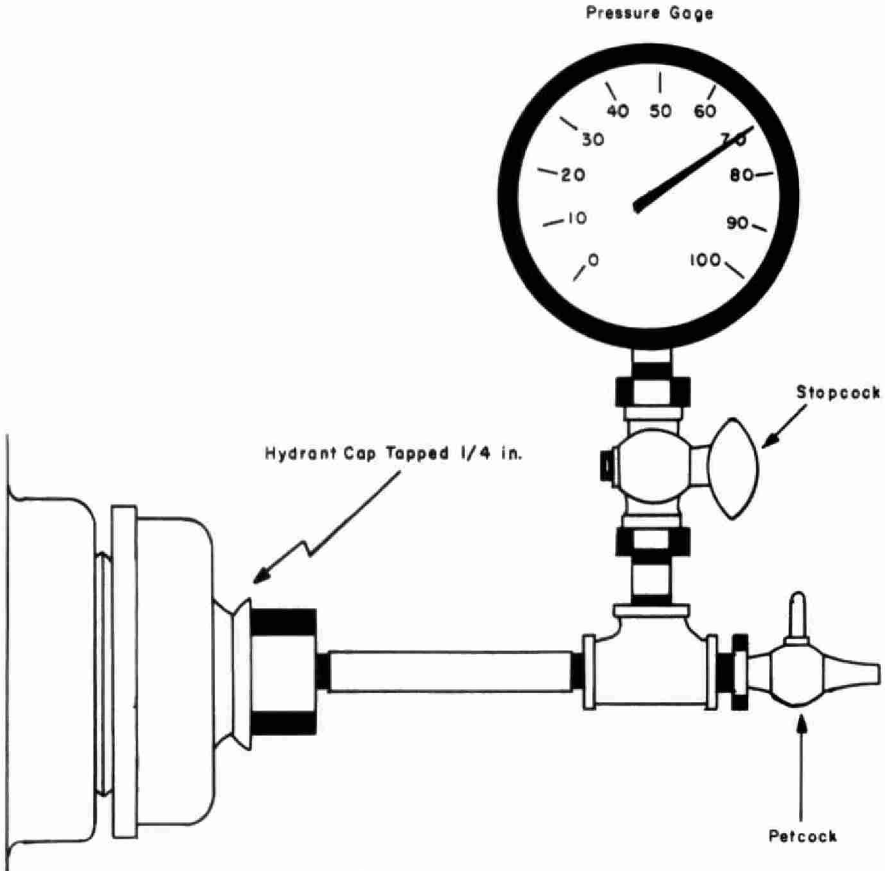


FIG. 5



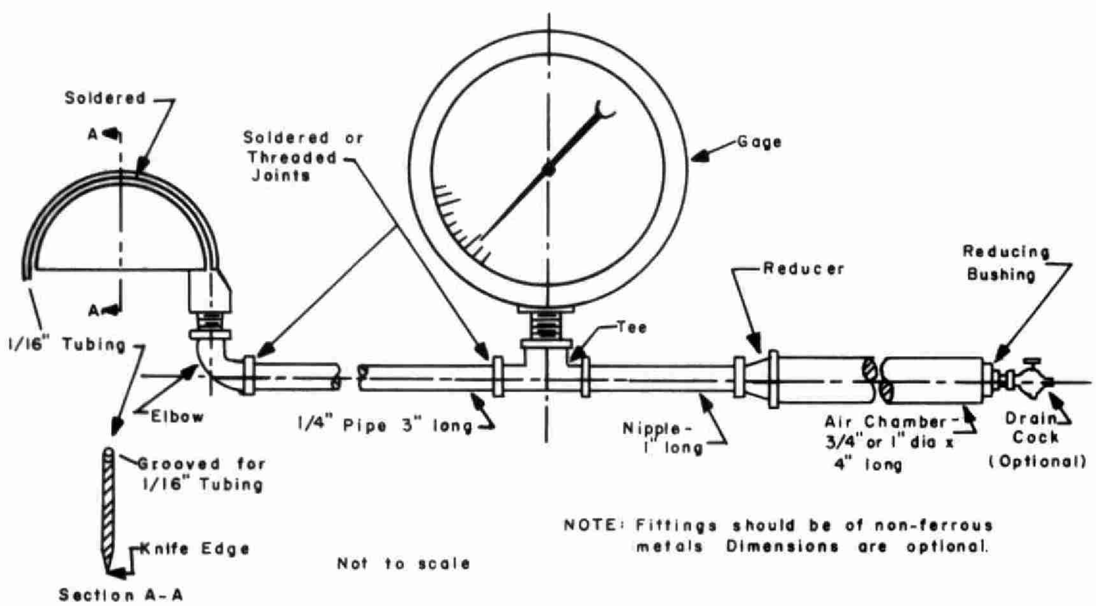
Scale Full Size
To be of brass and finished smooth

FIG. 6 Nozzle Stream Pitot.



Gage Assembly for Measuring Hydrant Pressures

FIG 7



Pitot Tube Assembly.

FIG 8

SOFTENING AND IRON REMOVAL

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District Engineer

INTRODUCTION

It has been said of water that it is the universal solvent. This is so since more things can be dissolved in water than in other known liquid. In the majority of cases this property of water is beneficial. In the matter of water treatment, however, the ability of the water to dissolve certain substances does, in cases, create certain problems.

Initially, water as it falls as rain is relatively pure with the possible exception of a few atmospheric impurities. As the water falls or gravitates into and through the soil and rock, however, a variety of substances are dissolved which result, in some cases, in the water becoming highly mineralized. Iron and hardness are the two most troublesome impurities which result from this activity which leads to serious staining, unpleasant tastes, scaling, wastage of soap, deterioration in equipment to name only a few.

It will be the purpose of this lecture to describe briefly the various methods of treatment employed in the de-mineralization of water. As a word of caution to some of you, these processes are best explained through Principles of Chemistry.

WATER SOFTENING (Removal of Hardness)

DEFINITION OF HARDNESS

There are two types of hardness both of which are caused by specific mineral salts:

a) Temporary hardness (carbonate hardness) - this is due to the presence of carbonates and bicarbonates

of calcium and magnesium and is referred to as being temporary since it can be removed by boiling.

b) Permanent hardness (non-carbonate) - this is due to the presence of sulphates and chlorides of calcium and magnesium and is permanent because it is not affected by boiling.

The amount of each of these mineral salts that can be dissolved in water varies. All of them are soluble to some degree and unfortunately most are soluble to a degree which results in concentrations high enough to cause problems. As a guide as to what follows we will consider that the most desirable concentration of hardness is approximately 50 to 60 ppm.

METHOD OF TREATMENT

1. Lime-Soda Softening

It should be noted that calcium carbonate, a mineral salt which produces temporary hardness in water is soluble only to a concentration of approximately 20 to 30 ppm. On the other hand, calcium bicarbonate is soluble to a much higher degree. Therefore, in the case of carbonate hardness, if the bicarbonates can be converted to carbonates, we would accomplish a reduction in hardness from high concentrations to acceptable limits. This would not only require that the calcium bicarbonate be converted to calcium carbonate, but that the unsoluble carbonates be removed from the water.

It has been found that this is readily accomplished by the addition of lime (calcium hydroxide). The chemical reaction is as follows:

$$Ca(HCO_3)2 + Ca(OH)_2 = 2CaCO_3 \downarrow + 2H_2O$$

Calcium Bicarbonate	Lime	Calcium Carbonate	Water

The calcium carbonate so formed, being insoluble, becomes a precipitate which can be removed by gravitational settling and filtration. The reaction is the same for magnesium and is indicated as follows:

$$Mg(HCO_3)_2 + Ca(OH)_2 = MgCO_3 + CaCO_3\downarrow + 2H_2O$$

Magnesium Bicarbonate	Lime	Magnesium Carbonate	Calcium Carbonate	Water

In the case of magnesium carbonate it is noted that this compound is soluble. The addition of more lime will result, however, in the production of magnesium hydroxide from the magnesium carbonate which is insoluble, and can be removed as in the case of calcium carbonate. The reaction is given as:

$$MgCO_3 + Ca(OH)_2 = Mg(OH)_2\downarrow + CaCO_3\downarrow$$

For interest it will be noted from the above equations that it takes exactly twice as much lime to remove a given amount of magnesium bicarbonate hardness as it does to remove an equal amount of calcium bicarbonate hardness.

In a similar way permanent hardness (non-carbonate) can be removed by the addition of soda ash (sodium carbonate) in place of lime. The chemical reaction is as follows:

$$CaSO_4 + Na_2CO_3 = CaCO_3\downarrow + Na_2SO_4$$

Calcium Sulphate	Sodium Carbonate	Calcium Carbonate	Sodium Sulphate

In regard to the physical operations in the lime-soda process it is noted that they are similar to the conventional coagulation, sedimentation, and filtration process for turbidity removal. However, since the lime-soda process leaves water super-saturated with calcium carbonates, carbon dioxide may be introduced prior to filtration to dissolve any calcium carbonates which remain in suspension thus preventing its deposition on the filters or in the distribution system. To affect this reaction, alum, which is normally added to the sedimentation basin to promote settling promotes the generation of carbon dioxide to react with calcium carbonate to hold it in solution.

In regard to the disposing of the lime softening sludge it is not a satisfactory procedure to remove this from the settling tanks intermittently since it decreases settling

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capacity. Newer plants are now providing facilities for the continuous removal of this sludge, ultimate disposal being accomplished by lagooning.

2. Ion Exchange Softening

Like most chemical compounds, the properties can be altered by either adding, removing or replacing one element with another. This property permits the removal of hardness by what is referred to as "ion exchange". The process is simple in that the calcium and magnesium ions, which are part of the mineral salts, are passed through substances, the most common known as sodium zeolite, in which there is an exchange of "partners" which results in a compound being formed which does not contribute to hardness. The chemical equation can be simply stated as follows:

$$Na_2(Z) \quad + \quad Ca(HCO_3)2 \quad = \quad Ca(Z) \quad + \quad 2NaHCO_3$$

Sodium Zeolite	Calcium Bicarbonate	Calcium Zeolite	Sodium Bicarbonate

In this equation the exchange substance which is a complex chemical is referred to as "Z".

As a further explanation, calcium and magnesium ions are retained in the zeolite substance itself being contained in a compartment, much like a sand filter. The sodium bicarbonate which is formed by replacement is carried in the water and does not possess any of the properties related to hardness. The amount of water that can be treated through exchange units, of course, is dependent on the size of the unit employed. One advantage of ion exchange softening with sodium zeolite media is that it can be regenerated by passing through it a strong salt solution. The equation is as follows:

$$CaZ \quad + \quad 2NaCl \quad = \quad Na_2Z \quad + \quad CaCl_2$$

Calcium Zeolite	Sodium Chloride (salt)	Sodium Zeolite	Calcium Chloride

The solution of calcium chloride, the product of regeneration is wasted to the sewers during the regeneration cycle.

This method of hardness removal is extremely effective and will produce a hardness of zero until the exchange capacity of the unit is used up. However, water of zero hardness is both corrosive and much softer than desirable for ordinary use. In this case the problem is easily overcome by by-passing enough unsoftened water to be mixed with the softened water so that the resulting hardness of the water supplied for use is approximately 60 ppm.

IRON REMOVAL

Iron-bearing waters, as the name suggests, are due to the presence of the metal iron which is dissolved in the water in a number of various forms. In order to effectively treat the water it is necessary first to determine exactly what form the iron is in.

This will be one or more of the following four forms:

1. Soluble Ferrous Bicarbonate
2. Soluble Ferrous Sulphate
3. Soluble Organic Iron
4. Suspended Insoluble Ferric Hydroxide

As a guide to the discussions which follow it is noted that iron in water should not exceed a concentration of 0.3 ppm.

1. Ferrous Bicarbonate

Ferrous bicarbonate, which exists only in solution, is a colourless salt that can be found in deep wells or spring waters in excessive concentrations. It will be noted where the water containing ferrous bicarbonate is concerned that upon prolonged exposure to the atmosphere a whitish haze will appear which will gradually darken. Ultimately, a yellowish to red-brown precipitate forms. The precipitate is Ferric Hydroxide and it is this insoluble material which stains and discolours virtually everything with which it comes into contact. The formation of the precipitate mentioned suggests methods by which this form of iron can be removed.

They are:

a. Aeration, Settling and Filtration
b. Cold Lime-Soda Process
c. Zeolite Process

a. Aeration, Settling and Filtration

Chemically, when ferrous bicarbonate is in contact with air and particularly the oxygen, the following reaction occurs:

$$4Fe(HCO_3)2 \quad + \quad O_2 \quad + \quad 2H_2O \quad = \quad 4Fe(OH)3 \quad + \quad 8CO_2$$

Ferrous Bicarbonate	Oxygen	Water	Ferric Hydroxide	Carbon Dioxide

This oxidation can be effected as well by the addition of chlorine, air being used more frequently since it is free. Another advantage of utilizing air is that it will form CO_2 which is released from the water as gas thus having the effect of raising the pH. It should be noted that aeration is most effective if the pH of the water is above 7.0 whereas chlorination is more effective at a pH between 5 and 7. In some cases, therefore, the addition of chlorine to waters having a low pH is used as secondary treatment after the largest amount of the iron has been removed by aeration.

Several types of aerating devices are used, the most common of which employs the free fall of water through the air. With arrangements of splash-boards and the like, the contact surface between air and the water is increased to provide maximum removal. Other units supply air through mechanical diffusers. Following the introduction of air the water is allowed to stand in a detention tank prior to being discharged to some type of filter.

b. Cold Lime-Soda Process

Since most iron-bearing water is also hard water, the lime-soda process can be used which provides for the simultaneous removal of the iron and hardness. The iron removal is highly efficient due to the usually high pH values prevailing thus producing a rapid production of the insoluble

Ferric Hydroxide. The equipment to accomplish this consists of aeration facilities, chemical feeders, settling tanks and filters. Systems of this nature which are treating water containing high concentrations of iron often result in improved hardness removal as a result of the action of Ferric Hydroxide on the calcium carbonate and magnesium hydroxide precipitates.

c. Zeolite Process

In a similar fashion the zeolite softening units will remove iron as ferrous bicarbonate by the replacement phenomona as indicated in water softening. It should be noted that these units are not practical for iron removal without any softening and the application of these exchange units are usually limited to places where the iron concentration is not greater than 1 ppm to 30 ppm of hardness.

The magnesium zeolite process (rather than the sodium zeolite referred to under softening) will remove iron from water but it does not soften. Again this is applicable to waters containing not more than approximately 1 ppm of iron. This process is termed contact filtration and is accomplished simply by filtering the water through the magnesium zeolite which oxidizes the iron to an insoluble form. The accumulations are periodically removed by back-washing and regeneration is accomplished by a solution of potassium permanganate.

2. <u>Ferrous Sulphate</u>

Ferrous sulphate is usually found in acid waters and these waters usually originate in mining districts. Usually in these cases, these acid waters, particularly those originating below the surface, have most of the iron present as ferrous bicarbonate. This occurs as the water passes through limestone strata which neutralizes most of the free sulphuric acid and some of the ferrous sulphate to form calcium sulphate, carbon dioxide and ferrous bicarbonate. Treatment usually consists of aeration, neutralization with lime, soda ash or caustic soda, settling and filtration and, in cases where softening is also required, the cold lime-soda process can be used.

3. Organic Iron

In highly coloured waters, usually surface supplies from swampy areas, iron may be present in an organic form. In this regard neither aeration, chlorination or zeolite treatment is of much value. However, the conventional coagulation with alum and subsequent settling and filtration is effective.

4. Ferric Hydroxide

We have already mentioned Ferric Hydroxide and have seen that this can be produced by aerating water containing ferrous bicarbonate. In some cases the water, during its use prior to discharge, may well come into contact with air. This is particularly true in cases of shallow wells and the pumping of water by air lift. In these cases ferrous bicarbonate has already been oxidized prior to its use. Not all the ferrous bicarbonate, however, will be converted to Ferric Hydroxide since in these cases the amount of air available for oxidation is limited. To remove the Ferric Hydroxide first ensure that complete aeration of the water has been effected and then proceed with settling and filtration as before.

IRON BACTERIA

Associated with iron-bearing waters is the presence of what is termed"iron bacteria". These are filamentous organisms which are really a higher form of plant life than bacteria. The most common one is known as Crenothrix. These develop in clumps or slime attached to the walls of distribution pipes and may be present in reservoirs, stagnant ponds and ground-water supplies. Usually complaints which involve flakes of grey or brown masses of stringy or massive growths in water would indicate their presence. In difficult cases a prolonged accumulation of these organisms in water produces serious taste and odour problems. The simplest method of controlling their growth is to remove the iron from the water before it enters the distribution system. This in effect, deprives the organisms of food.

ELECTRICAL MOTOR MAINTENANCE

John P. Dawson, Manager

Dunnville Public Utilities Commission

This is going to be a talk to you about electricity and motors. You will be asked to answer one question from this talk and I am going to reverse the usual idea. I am going to list for you now the questions. You will be given the answers in my talk. Do not get worried, only one of the ten questions will be on the exam.

1) How would you tell when a motor is too hot?
2) What would you do if a motor control turned itself off?
3) How often do you grease a ball bearing motor?
4) What does a gap gauge tell you?
5) What are phases in electrical language?
6) Why does a motor run?
7) How would you reverse a three-phase motor?
8) What is a volt similar to in water?
9) Are all horsepower values the same?
10) A motor stops, what should you do first?

The answers are not going to be hard or tricky. The answer to number (8) is that a volt is the same as pounds pressure in water, so the answer is "lbs. per sq. in." or "pounds pressure".

You are water works men and you are all familiar with the way water behaves and so I am going to tell you how electricity behaves in water terms and my talk will try to show you, by comparison, what that energy, we all use, acts like.

Electricity is energy and it flows just like water and it behaves very much like water, only it is much faster. You all know that if you turn a valve on that there is a time before water travels a long distance.

There is the story about a very tough waterworks boss who used to blast at his men because when they were laying 6" pipe they needed more than six lengths head start if he turned on the water for them to keep ahead of the water.

Water travels very fast, especially when we do not want it to, but electricity travels many times faster. If there was a wire around the earth and you were able to tie a flag on a little bit of electricity so you could watch the little bit go by on the wire, the little bit of electricity would go 25,000 miles around the earth and it would go by 7½ times a second. The electricity would go all around the world 7½ times every second. That's far too fast for you and me to even understand.

Each time the little bit of electricity passed by on the wire it caused a wave of magnetism to go with it, but more of that later.

Now, how does it travel? It is easy - It is just like a bunch of pool balls after you frame them. They are all touching one another and just shoot the cue ball and all the balls in the centre do not seem to move, but the balls on the far side from where the cue ball hits - shoot off.

They tell us that copper wire is made up of little pieces and that each piece bounces back and forth as the electricity passes by and the energy is moved from one end of the wire to the other, but the little pieces of copper do not actually travel along the wire. It would be the same as if I were able to line you all up in the hall with your feet firmly planted on the floor and your shoulders touching and then I gave the end man a good push. Not enough to move his feet, but his shoulders would push the next man and the push would travel along the line to the last man and he might fall over.

In water the amount of push is shown on a pressure gauge reading in pounds per inch usually, and in electricity the pressure gauge reads in volts, so a volt is the same as pounds per inch. How far the push went would read as gallons per minute and would show on a flowmeter to show the rate and in electricity this is an ammeter.

In water the amount of push and distance the push went would show on an ordinary water meter reading in gallons or cubic feed and in electricity this would show on a watt meter.

How hard it was to push all you guys would be the same as how rough the pipe is in waterworks and would be the resistance of the pipe and you would know it as loss of head or pressure drop, and it would be measured at a waterworks by comparing two pressure gauges. This is resistance to the flow of water and is measured as pounds drop and in electricity it too, is resistance and is measured in ohms.

You, at home, buy water at so much pressure in pounds per inch. You buy electricity at so many volts - you buy so many gallons of water, in electricity you buy so many watts. The water flows at so many gallons a minute and electricity flows in amperes.

You all know that water moves in waves when it gets rough out on a lake, but the actual water does not actually travel, except along the shore, only the wave action moves. This wave action can do a great amount of damage and has tremendous power when it hits anything that is solid. The electricity you use travels in waves and around here the waves go up and down 60 times a second, this is 60 cycle power. A cycle is merely a top of a wave called a crest and bottom of a wave called a trough. In a lake the top moves forward a very little bit and the trough moves back so the water stays almost in the same place. It behaves very much the same in electricity, except the waves are waves of magnetism.

If you have a boat out in the lake it will go up and down on the waves and they must use some of their power to lift the boat, but the wave goes right on -- I hope I am not making any of you seasick -- This may be likened to the result of electricity in waves or cycles going past a coil of wire which would be the same as the boat. The electricity uses some of its power getting past the coil, but the waves go right on. If you were out in the boat you might get seasick, but if you were in the coil you would become magnetized.

As waterworks men, you all have to deal with motors of various sorts. Waterworks started with steam engines to do the pumping and those of you who were able to go to Buffalo to the waterworks there, saw some mammoth steam engines driving huge pumps. The actual flywheels would be at least three storeys high and the men to lubricate the valve chamber climbed as high as this building. The coal for the boilers was

delivered in coal cars which ran on tracks above the boilers. We were there about eight or ten years ago and they had replaced one of the huge engines with an electric motor about eight feet high.

The electric motor was about 1,000 horsepower
The steam engine was about 750 horsepower
A gasoline engine would be about 3,500 horsepower
A diesel engine would be about 2,000 horsepower

These variations in horsepower are chiefly due to the speed at which it is measured.

A horsepower was defined by Watt, who is credited with the invention of the steam engine, as the amount of work a good horse could do and it is set forth as 2,000 ft. pounds per minute. This goes back to our electrical equivalent of watts that I tried to describe to you as an amount of work and it is 746 watts equal one electrical horsepower.

An electric motor is a machine to change electrical energy into mechanical energy.

A water wheel is a machine to change water energy into the form of falling water into mechanical energy.

In Ontario, we started using the energy of falling water at Niagara to drive a mechanical shaft that turned a generator that made electrical energy. This electrical energy can be carried by wires to your pumphouse and converted back again to drive a pump to lift water. As waterworks operators, you are concerned with changing electrical energy back to mechanical energy to drive the pumps.

The electrical motor consists of a frame to hold the working parts together and to keep them in proper relationship, one to another. The frame is usually painted to look nice and to make it easy to keep clean. Inside the frame is the stator - it stays still and the business part of the motor is the rotor - it rotates on bearings. These bearings hold the shaft that supports the rotor and allow it to turn. The shaft transmits the turning effect from the rotor to the load.

I am not going to explain complicated motors to you, so do not get worried. A motor is a hard working piece of stuff and, to be efficient, it must be fairly solidly built and to quite close limits. The closer the part that goes round - the rotor - can be to the part that surrounds it - the stator - the better - so the bearings should be good. Ball bearings are more and more being used because they can be accurately machined and, at present, large stocks are carried of stock sizes so that replacements are available. Ball bearings need less lubrication that any other type and they suffer more from over-lubrication rather than lack of lubrication, so do not ever grease a ball bearing with a grease gun unless there is a hole for excess grease to get out while you grease. The manufacturers will tell you how often to grease, but every six months is lots for bearings running all the time. A ball bearing that runs hot is most likely overgreased.

If the motor has sleeve bearings, make sure the rings are carrying oil. If you have a chance to check a pump that has a sleeve bearing motor, or, for that matter, any motor that you check, the very first thing to do is make sure the switch is pulled and, if possible, lock it open. If you cannot lock it open and you can see it - keep your eye on it. A sleeve bearing motor should be checked with a gap gauge to find out whether the bearings are worn. The gap gauge is a thickness gauge and it is used between the stator and the rotor. It should go in between the two at the bottom as easily as at the top. If there is more space at the top on a motor that is horizontal than there is at the bottom, it means that the bearings are worn and this has allowed the rotor to settle. Arrange to have the trouble remedied as soon as possible by the replacement of the bearings.

When electricity flows through a motor it produces magnetism, the same kind of stuff you played with as a kid when you had a horseshoe magnet and picked up needles and pins. Today there are dozens of magnets in every house, because television and radio depend on them, the meter on the wall depends on them, most clocks work with them and so the list goes. Your car cannot operate without magnetism.

The magnets that are in a motor are big magnets and they are created by the waves of electricity and they change as the waves change. They get stronger and weaker 60 times a second, just as there are 60 waves a second. These magnets are manufactured

into the stator and they make magnets by induction in the rotor, just the way a nail becomes a magnet when it is near a magnet, so the motor is called an induction motor. There are three sets of magnets in the ordinary three phase motor and they are connected to three wires and the three wires connect all the way back to the generator that was turned by the water-wheel at Niagara. These wires are all carrying electricity in waves, but one wire is carrying a crest of its wave a little bit behind the one ahead and the last wire has its crest still further behind. The waves are the same size and shape, but they are timed to follow one another. The timing is called phasing and so we have three-phase power, because one is timed behind the other. Do not worry about it, just remember that phases mean timing.

Now, to get back to our motor. Our wire has a crest of a wave and it makes its magnet strong and the rotor is attracted to the magnet and to get near it, it turns on its bearings to where the magnet is strong, but, by now, the crest of the wave that made that magnet strong has moved on and the next magnet is strong and so the rotor has to move on to bearings to get to the next magnet and this keeps on from magnet to magnet. It is just like that dirty old trick of tying a carrot on a stick and fastening it on the donkey. Each time the donkey took a step forward to get the carrot, of course, the carrot moved ahead. So with the motor, the rotor of the motor never quite catches the magnet because the magnet moves ahead each time the rotor almost gets there. You can see that with three phases each taking one-third of the space, the rotor moves from 1 to 2 to 3 to 1 to 2 and so on, and there are 60 waves on each wire so the motor turns at a speed usually in the 1,800 range for pump duty. By changing any two wires feeding the motor, say 2 and 3, we get 1 to 3 to 2 to 1 to 3 to 2 to 1 and the motor runs the opposite direction - it is as easy as that.

The more load that is put on a motor the more electricity has to flow to keep it turning and this causes heat. A rule of thumb about a motor is that if you can lean on a motor with your bare hand it is not dangerously hot. There are different types of motors now that are not dangerously hot when you cannot lean on them, but they usually are specials. If a motor has a modern motor control unit, the unit will be set so that it will turn the motor off before it harms itself,

and if a motor stops without any reason and you find when you check the controls that it has turned itself off, be sure before you try to start it up again that the cause of the stoppage has been corrected - it may be a bad bearing in the motor, or it may be pump trouble. Before you check any of these be sure to open the switch that supplies the control - do not monkey with live electrical equipment. They say death is so permanent.

Just remember, that electricity, like fire, is a wonderful servant but a terrible master. Be sensible, keep control of electricity and use your servant.

INTERMEDIATE MATHEMATICS

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The lecture given in the basic course dealt primarily with the fundamentals of mathematics. With this knowledge of fundamentals we may now go on to apply what was discussed during the basic lecture to the every day operation of water works systems.

Conversion Factors

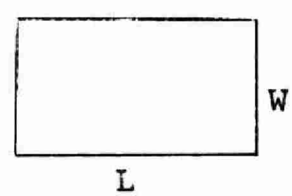
A complete table of conversion factors has been provided in the basic mathematics lecture. The common conversion factors are listed below for handy reference.

1 cubic foot	=	62.4 pounds
1 cubic foot	=	6.24 gallons
1 gallon	=	10 pounds
1 gallon per minute	=	1,440 gallons per day
1 cubic foot per second	=	539,000 gallons per day
1 cubic foot per second	=	375 gallons per minute
1 grain per gallon	=	14.3 parts per million
1 Imperial gallon	=	1.2 US gallons
1 US gallon	=	0.833 Imperial gallons
1 pound per square inch	=	2.31 feet of head

Example 1

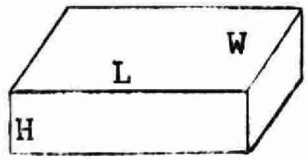
A rectangle is 7 inches long and 4 inches wide. What is its area?

$$\begin{aligned} A &= L \times W \\ &= 7 \times 4 \\ &= 28 \text{ square inches} \end{aligned}$$



If the rectangle above were to cover a box 3 inches deep, what would the volume of the box be?

$$V = L \times W \times H$$
$$= 7 \times 4 \times 3$$
$$= 84 \text{ cubic inches}$$

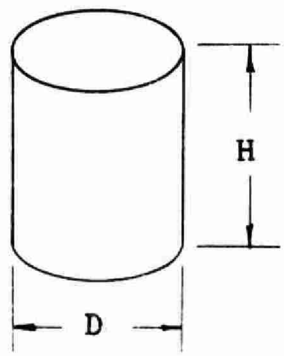


Example 2

A cylindrical tank 5 feet in diameter is filled with lime slurry to a depth of 11 feet. Assuming it can be drawn down to a level of 1 foot, how many gallons of lime slurry will be drawn off?

Volume of cylinder

$$= \frac{\pi D^2}{4} \times H \qquad D = \text{diameter}, \; H = \text{height}$$



$$= \frac{3.14 \times 5^2 \times 10}{4}$$

$$= \frac{3.14 \times 25 \times 10}{4}$$

$$= 196.2 \text{ cubic feet}$$

Since 1 cubic foot = 6.24 gallons, the amount of slurry drawn off

$$= 196.2 \times 6.24$$

$$= 1,224 \text{ gallons}$$

Example 3

A sedimentation basin is 100 feet long, 25 feet wide and 10 feet deep. What is its volume in

(a) cubic feet?
(b) gallons?
(c) million gallons?

(a) $V = L \times W \times H$
$= 100 \times 25 \times 10$
$= 25,000$ cubic feet

(b) $= 25{,}000 \times 6.24$
$= 156{,}000$ gallons

(c) $= \dfrac{156{,}000}{1{,}000{,}000}$
$= 0.156$ million gallons

What would be the volume of water in the same sedimentation basin if it contained 8 feet of water, in

(a) cubic feet?
(b) gallons?
(c) million gallons?

Since the depth of water in the tank is now 8 feet instead of 10 feet the answers become

(a) $\dfrac{8}{10} \times 25{,}000$
$= 20{,}000$ cubic feet

(b) $\dfrac{8}{10} \times 156{,}000$
$= 124{,}800$ gallons

(c) $\dfrac{8}{10} \times 0.156$
$= 0.1248$
$= 0.125$ million gallons

If the flow-rate through the tank is 500 gallons per minute what is the detention time in hours at the 8-foot depth?

500 gpm $= 500 \times 60$
$= 30{,}000$ gallons per hour

Volume of tank
$= 124{,}800$ gallons

Therefore, detention
$= \dfrac{124{,}800}{30{,}000}$
$= 4.2$ hours

Example 4

A pump is capable of discharging 400 gallons per minute. What chlorine feed-rate is required to provide a dosage of 2.5 ppm?

$$400 \text{ gpm} = 400 \times 1{,}440 \times 10 \text{ lb of water per day}$$

Weight of chlorine required

$$= \frac{2.5 \times 400 \times 1{,}440 \times 10}{1{,}000{,}000}$$

$$= 14.4 \text{ lb per day}$$

Therefore, chlorine feed-rate required is 14.4 lb per day.

Example 5

A new 12-inch watermain 1,000 feet long is to be disinfected with an intended residual of 50 ppm. Assuming a 10-ppm chlorine demand, how many pounds of chlorine gas are needed?

$$\text{Volume of pipe} = \frac{\pi D^2}{4} \times 1{,}000$$

$$= \frac{3.14 \times 1 \times 1{,}000}{4}$$

$$= 785 \text{ cubic feet}$$

$$\text{Weight of water} = 785 \times 62.4$$

$$= 49{,}000 \text{ lb}$$

Since there is a chlorine demand of 10 ppm, the dosage must be 60 ppm to provide a residual of 50 ppm.

$$\text{Weight of chlorine} = \frac{60 \times 49{,}000}{1{,}000{,}000}$$

$$= 2.93 \text{ lb}$$

If calcium hypochlorite, 70 per cent available chlorine, were to be used in the above, how many pounds would be required?

$$\text{Weight of hypochlorite} \times 0.70 = 2.93 \text{ lb}$$

$$\text{Weight of hypochlorite} = \frac{2.93}{0.70}$$

$$= 4.2 \text{ lb}$$

Example 6

A total of 150 pounds of alum was added to a mixing basin during a 24-hour period. If the total flow during that period was 1.5 million gallons, what was the dosage in

(a) parts per million?
(b) grains per gallon?

(a) $\frac{150 \times 1{,}000{,}000}{1{,}500{,}000 \times 10} = 10 \text{ ppm}$

(b) $10 \text{ ppm} = \frac{10}{14.3} \text{ gpg}$

$= 0.7 \text{ gpg}$

Example 7

The recommended dosage of Calgon for the control of "red-water" problems is 2 ppm Calgon for each 1 ppm of iron in the raw water. If the iron content in a water is 1.35 ppm and the average daily consumption is 750,000 gallons, how many pounds of Calgon are required per day?

$$\text{Dosage of Calgon} = 2 \times 1.35$$
$$= 2.70 \text{ ppm}$$

$$\text{Daily requirement} = \frac{2.70 \times 750{,}000 \times 10}{1{,}000{,}000}$$

$$= 20.25 \text{ pounds}$$

Example 8

An aeration device at an iron-removal plant is expected to reduce the iron content of the water from 2.3 ppm down to 0.3. If the average daily flow-rate is 100,000 gallons, how many pounds of iron would be removed?

2 ppm are removed

100,000 gallons = 1,000,000 lb

$$\text{Therefore, } \frac{2 \times 1{,}000{,}000}{1{,}000{,}000}$$

= 2 lb are removed

Example 9

The recommended average rate of flow through rapid sand filters is 2 US gallons per minute per square foot. The average daily flow through a filter having dimensions of 12 feet by 20 feet is 1 mgd (US). Is the filter overloaded?

Area of filter = 12 x 20
= 240 sq ft

$$1 \text{ mgd} = \frac{1{,}000{,}000}{1{,}440}$$

= 695 gpm

$$\text{Filter rate} = \frac{695}{240}$$

= 2.9 gpm per sq ft

Therefore it is overloaded

Example 10

The totalizer readings on a meter which times the operation of a pump in hours were 6863 and 6897 at the beginning and end of a pumping period. If the pump is rated at 375 gallons per minute, how many gallons were pumped?

No. of hours of pump operation

$$\begin{array}{r} 6897 \\ -\ \underline{6863} \\ 34 \end{array} \text{ hours}$$

No. of minutes of pumping

$$34 \times 60 = 2{,}040 \text{ minutes}$$

Total pumpage

$$375 \times 2{,}040 = 765{,}000 \text{ gallons}$$

Example 11

The meter readings at a water works at the beginning and end of a 5-day period were 65271 and 65846. If the meter readings represent 1000's of gallons, what was the average daily consumption?

$$\text{Pumpage} \quad = \quad \begin{array}{r} 65{,}846{,}000 \\ -\ \underline{65{,}271{,}000} \\ 575{,}000 \end{array} \text{ gallons}$$

$$\text{Average day} \quad = \quad \frac{575{,}000}{5}$$

$$= \quad 115{,}000 \text{ gallons}$$

If there were 250 homes on the system, and assuming each used the same amount, how much did it cost each home-owner if the water sold at the rate of 41¢ per thousand gallons?

$$\text{Usage per home-owner} = \frac{115,000}{250}$$

$$= 460 \text{ gallons}$$

$$\begin{aligned}\text{Cost} &= 0.460 \times 0.41 \\ &= 19¢ \text{ per home-owner}\end{aligned}$$

Example 12

If the water level in an elevated storage tank is 165 feet above the adjacent pumphouse pressure gauge, what should the gauge read in pounds per square inch?

1 pound per square inch = 2.31 feet

Therefore, gauge reading

$$= \frac{165}{2.31}$$

$$= 71.4 \text{ psi}$$

Example 13

The velocity of the water moving in a 12-inch pipe is 3 feet per second. What is the flow in

(a) cubic feet per second?
(b) gallons per minute?

The flow is equal to the velocity times the area of the pipe

$$\begin{aligned}Q &= VA \\ V &= 3 \text{ fps} \\ A &= \frac{\pi D^2}{4} \qquad D = 12 \text{ inches} = 1 \text{ foot} \\ &= \frac{3.14 \times 1^2}{4} \\ &= 0.785 \text{ square feet}\end{aligned}$$

$$\begin{aligned}\text{(a)} \quad Q &= 3 \times 0.785 \\ &= 2.355 \text{ cubic feet per second}\end{aligned}$$

$$
\begin{aligned}
\text{(b)} \quad Q &= 2.355 \times 375 \\
&= 883 \text{ gpm}
\end{aligned}
$$

Example 14

A solution is made up of 10 pounds of chlorine, 30 pounds of water and 10 pounds of lime. What is the per cent of each of the three components in the mixture?

The total weight of the mixture is 50 pounds.

$$\text{Per cent of chlorine} = \frac{10}{50} \times 100 = 20$$

$$\text{Per cent of water} = \frac{30}{50} \times 100 = 60$$

$$\text{Per cent of lime} = \frac{10}{50} \times 100 = \underline{20}$$

$$\text{Total} \quad 100$$

BACTERIOLOGY II

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In order to better understand the elimination of a microbial population, some factors influencing its existence must first be considered. It is said that water requires treatment, in order that it may be rendered safe for consumers and to ensure that it is wholesome, sparkling and clear. To fulfill this obligation, any treatment process is required to remove suspended and dissolved mineral or organic material, or neutralize substances of a poisonous nature and to kill disease and nuisance producing organisms that may be present from time to time. Before a source of water can be considered suitable and before treatment that it may require can be determined, factors influencing these criteria must first be taken into consideration.

Basic to understanding the problems involved are the following points: Organic matter such as sewage or decaying vegetation will induce a high bacterial population. In some natural waters, the microbial density is roughly proportional to the amount of organic matter present, with a larger variety of organisms present in clean waters. This relationship between organic matter and an increase in microbial population, is of great importance, particularly where constant large quantities of dissolved organic matter are involved. In this case, nutrients become available to bacteria existing in the water mains following treatment and cause rapid microbial growth which eventually may create a nuisance. Polluted waters generally support larger populations of fewer varieties or organisms. An example that may be cited, is the large numbers of coliforms and other intestinal bacteria present in water receiving discharge from a sewage plant.

SURFACE WATERS

(1) Flowing Water

Flowing water in streams will tend to purify itself more rapidly than quiescent water. The organic matter, in the presence of oxygen entering the water by surface aeration, riffles and rapids, and as a by-product of the growth of algae, is rapidly degraded by the microorganisms. The number of species of organisms present will depend upon the manner and type of waste discharged upstream.

If the waste is chlorinated, the microbial population will be reduced by 70% to 99%, and factors such as dilution will have to be relied upon, to reduce the toxic effects of chlorine before degradation of organic matter in the natural purification cycle can take place. In some cases the polluted zone will be extended further down the river, until the microbial population recovers (aftergrowths) and degradation is accomplished. Excessive doses of disinfectant (chlorine, etc.) in waste treatment may be effective in avoiding septic conditions in a populated area (for example) but it must be realized that the zone of heavy organic pollution is merely pushed further downstream by this practice.

Temperature and pH are two other major factors affecting the zone of pollution in a stream and, therefore, require considaration. Lower temperatures will slow microbial activity causing extension of the polluted zone. A high pH will restrict bacterial growth with the result that degradation of organics will become largely a fungal process. Water containing minute bacterial bodies will be more easily filtered than that containing fungal filaments. These factors are of importance in arriving at the location of a suitable intake, if efficient, safe and economical water treatment is to be achieved.

Control of the temperature, pH and other factors that may effect the amount of organic material and eventually the microbial population, is not always possible. However, by controlling pollution around the catchment area, by excluding humans and larger animals, significant reduction in the amount of organic material reaching a stream as well as a gross reduction in coliform content may be had. Some organic material will pass into the water from the land, vegetation and from small animals and birds, but it has been shown that the water will very likely have low coliform numbers and substantial reductions in the quantity of organic material will be observed.

(2) Impounded and Still Waters

Quiescent waters are usually much slower in stabilizing the organic compounds therein and the factors responsible for this slower rate of degradation are poor aeration, temperature variation, and sedimentation. Aeration in this case depends upon wave action, convection currents, wind and algae. In shallow ponds the growth of algae may play a greater role in the aeration of water, however, as the depth of the water increases, the effect of algae on aeration will generally decrease substantially. Seasonal temperatures will have a greater effect on a standing body of water. Each season a complete turnover of organisms capable degrading organic material

will occur and during this period, the rate of degradation will be interrupted awaiting the development of a new flora. Sedimentation of suspended particles will also carry down part of the micro-flora. The organic material in clumps and suspended microbial bodies may both be taken away from the zone rich in oxygen thereby further slowing down the degradation process.

(3) Ground Water

A ground water supply is often considered the source of the best quality water and often it is. If the water is not too hard and does not contain quantities of objectionable minerals - notably iron, sulfur compounds or chlorides - and is properly managed, it will provide a good water. However, those who have considered ground water as the supply that requires no management beyond pumping have been sadly deceived.

Disregarding for the moment contamination from surface sources, taste and odour, and "red water" problems may readily develop if particular attention is (1) not paid to construction details, (2) if the chemical characteristics of the water are not properly evaluated and (3) if long runs of slowly moving water are allowed. Ground water is often devoid of oxygen, devoid of large quantities of food that normal bacteria can utilize, contains dissolved gases such as carbon dioxide, and contains a bacterial population that can live in this environment. When extracted from ground, the equilibrium or balance existing among these chemical and physical systems is destroyed and will allow the mineral-loving organisms to grow unchecked. Iron and sulfur-loving bacteria already present in insignificant quantities in the ground water or introduced during well and pipe line construction, often find a suitable growing environment. They will accumulate iron, even if it is present in the water only in trace quantities, will produce hydrogen sulfide if sulfates are present, and will eventually degrade the aesthetic quality of the water. The eventual solution of these problems lies only in applying continuous chlorination.

However, these troubles can often be avoided by providing suitably designed stabilization basins for each well and during pipe line construction by avoiding sections of slow-moving water and looping dead ends. Dead ends that cannot be looped should be provided with a means of flushing.

Good management practices will provide periodic frequent cleaning and disinfection of stabilizing basins and frequent flushing in troublesome areas and dead ends. These details have been too often disregarded in the past and supplies that were once considered carefree must now be chlorinated to provide only acceptable water.

Numerous bacterial quality objectives have been established by various agencies for waters used as sources for potential potable supplies. Since many of these have been influenced by the United States Public Health Service recommendations, these should be stated here.

"For waters acceptable for treatment by conventional rapid-sand filtration with continuous postchlorination, the monthly average density of coliform organisms should not exceed 5,000 per 100 ml.; and not more than 20% of all samples examined during any month should exceed that density. The use of auxiliary treatment - prechlorination, pre-sedimentation, or the equivalent - does not permit an increase in the monthly average density of coliform organisms, but does permit more than 20% of these samples examined in any single month to exceed 5,000 per 100 ml., provided not more than 5% exceeds 20,000 per 100 ml."

Walton in 1956 reported that for several years water treatment plants have been producing acceptable drinking water from natural waters having coliform counts exceeding these recommendations. As a result of this and new techniques, frequent revision of the objectives is necessary.

The need for such an elaborate standard has not been felt necessary in Ontario; a coliform count of 2,400/100 mls. (which is an almost universally accepted bathing water standard) is realistic, and had been chosen for this purpose.

In order to fully understand these objectives, the efficiency of removal of microorganisms from water by the conventional methods of sedimentation, flocculation, filtration and chlorination should be discussed.

Sedimentation

Sedimentation reduces the bacterial count of water from 25 to 75% under normal conditions. The efficiency may increase depending upon the length of time that the water remains standing. Bacterial bodies do have weight and are subject to sedimentation.

Flocculation

The chemistry involved in flocculation has been dealt with by others, and only the effects of various flocs on the removal of microorganisms will be discussed in this section.

The critical time for the formation of the coagulant complex in relation to the removal of viruses and E.coli cells by practical doses of alum at 25°C., is thought to be confined to the first few minutes after the addition of the coagulant. Under laboratory conditions the removal of Coxsackie virus by 25 ppm alum in raw Ohio River water having turbidity readings under 260 ppm was 95 to 99% at 5 to 15°C. and 25°C. respectively. By reducing the amount of alum to 15 ppm, 95.7% removal at 25° was accomplished. However, under the latter conditions, about 99% of the E.coli cells and the total bacteria were removed. Removal of bacteria therefore by flocculation is far more efficient than the removal of viruses. It must be remembered however, that large populations of bacteria are being dealt with and a 99% removal when applied to the number of bacteria present in the untreated water may mean that tens and sometimes hundreds of thousands escape this treatment.

The virus removal efficiency when ferric chloride is used as a flocculant is comparable to that of alum, but the bacterial removal efficiency is somewhat lower as pointed out in the studies carried out by the U.S. Public Health Service. Calcium and magnesium ions are found to contribute to this lower bacterial removal.

Filtration

Intermittent rapid sand filters generally remove 90 to 95% of the bacteria while slow sand filtration removed from 95 to 99%. In our laboratory, we have found that some of the smaller filter units, of the type that may be adapted to a water faucet or the type that may be used in pool water filtration, often have the efficiency of slow sand filters. Virus removal figures are not available here and it is assumed that even greater inefficiencies in removal would be apparent.

Disinfection with Chlorine

Again chlorination in its varied forms and uses has been mentioned by others and the chemistry of chlorination has been explained. It is our intention here merely to bring out some of the details regarding the effectiveness of chlorination on the removal of vegetative bacteria, bacterial spores, viruses and cysts such as those of Endamoeba histolytica. Some factors already mentioned, include the contact time between chlorine and the microorganisms, the temperature and pH of the water. It seems obvious that the longer the contact time the more effective the disinfection. At lower temperatures and higher pH values, disinfectant becomes less effective in most cases.

Under the most favourable conditions, that is, at a pH of 7.0 to 7.6 and a water temperature of 20 to 25°C., almost 100% kills of vegetative bacterial cells can be obtained with combined available chlorine residuals of about 1.2 ppm in 20 minutes. Under similar conditions with free available chlorine, close to 100% kills are obtained with 0.04 to 0.05 ppm residuals in one minute of contact time.

To obtain a comparable kill with the same contact period requires about 25 times as much residual combined as free available chlorine in water is apparent.

Chlorine is not as effective as a sporicidal agent however. In the alkaline pH range and at normal air temperature (22°C.), a 99.999% kill of bacterial spores in 90 minutes requires free available chlorine residuals in the range of 2 to 450 ppm. A slightly acid pH range (approximately 6.2) and free available chlorine seems to be the most effective, though satisfactory kills still require a long contact time. At lower temperatures somewhat larger doses are required to produce the same sporicidal effect.

Chlorine as a cysticidal agent increased in effectiveness with an increase in temperature, contact time, as well as a lowering of pH. Cysts of E. histolytica for example will be killed by 5 ppm of free available chlorine at 22 to 25°C. at pH's of 8 or less in 30 minutes.

With respect to the effectiveness of chlorine on viruses, it has been stated that from 7 to 46 times as much free available chlorine must be used to obtain 100% kills. The different types of viruses, the amount of organic matter present and other minor factors are the cause of this wide variation.

In conclusion, the suitability of the source of water should be considered in the light of the amount of organic matter present and the character of any wastes it may contain. Physical agents such as sedimentation, flocculation and filtration at best, only reduce bacterial numbers. Chemical disinfection for waters, requiring any physical treatment, must be relied upon to remove vegetative bacteria and reduce the numbers of the remaining microflora.

CHEMICAL FEEDING EQUIPMENT

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INTRODUCTION

The increased use of our water supplies has made chemical feed a basic requirement of all water treatment plants. Gone is the day when a water supply could be delivered to the mains without at least chlorination. In this lecture we will discuss various methods of feeding these treatment chemicals. Some of the more common chemical treatment processes are listed in the following:

- Coagulation
  - Algae control
  - Turbidity removal
  - Colour removal
- Disinfection
  - Chlorination
- Fluoridation
- Corrosion control and scale formation
- Iron and manganese removal
- pH Control
- Softening
- Taste and odour control

There are three basic forms into which all matter can be divided. These are gases, liquids and solids and, therefore, there are likewise three types of feeders and we will deal with them in that order.

GAS FEEDERS

The discovery of the sterilizing properties of chlorine prompted the development of gas feeders, commonly called chlorinators. These same machines with some modifications to compensate for different corrosive properties were later used to feed ammonia and sulphur dioxide. The advent of the plastic age drastically changed the gas feeder and today most machines are constructed of P.V.C. (Polyvinylchloride), and can be used on any one of the three gases. Do not change machines from one type of feed to another.

Early machines were of the direct pressure type and consisted of a chlorine pressure reducing valve, commonly called a compensator, and a feed rate adjustment or valve. Modern day chlorinators operate on a vacuum principal with the entire unit under vacuum and, therefore, offer a high degree of safety.

TYPES OF FEED

A solution feed chlorinator is one in which the gas is first dissolved in a minor flow of water and the resultant chlorine solution fed to the desired point of application. An operating water pressure, 1.5 to 2 times the pressure against which the solution is to be introduced, is necessary to operate the chlorine solution injector.

The direct feed type is applicable to locations where water under sufficient pressure cannot be made available to operate an injector such as is used for solution feed chlorinators. In the application of chlorine to water under pressure, dry feeding is limited to back pressures of approximately 25 psi. Many difficulties have been encountered in the development of a diffuser that effectively disperses the chlorine and at the same time will not be subject to clogging and the need of frequent cleaning. In sections of the province where low temperatures are encountered, chlorine hydrate formation around the diffuser may interfere with satisfactory operation. If complete diffusion is not secured, undissolved chlorine gas will accumulate in pipelines, valve heads, and pumps causing corrosion.

TYPES OF FEEDERS

1. Vacuum Type

Vacuum type chlorine feeders meter chlorine gas, convey it through the apparatus under vacuum and employ an injector into which the gas is drawn to provide solution feed. In a full-vacuum type feeder, the vacuum governs the operation of the chlorine inlet valve. In this type of feeder which employs a direct indicating meter, the flow of chlorine is automatically shut off on loss of vacuum, stoppage of discharge line, or loss of operating water pressure. Present day chlorinators are all of the vacuum type.

2. Partial Vacuum Type

In the partial vacuum type feeder, which usually employs a direct indicating meter, opening of the chlorine inlet valve is not vacuum governed and the feeder will not automatically shut off flow of chlorine on loss of operating water pressure, loss of vacuum or stoppage of injector.

3. Pressure Type

Pressure type chlorine feeders are commonly used for direct feed. No safety is afforded against leakage since the gas is under pressure furing normal operation. Pressure feed devices consist essentially of a pressure reducing, pressure compensating valve by which, regardless of pressure variations in chlorine cylinders due to temperature changes, constant pressure drop may be maintained across an orifice which is measured and used as an indication of the rate of gas flow. Today this type of feeder is used only for ammonia.

4. Pulsating Type

Pulsating type feeders are similar to partial vacuumed type except the metering device is a volumetric pulsating unit and the rate of chlorine feed must be ascertained by timing the meter pulsations.

PLATFORM SCALE

Although not necessary, a platform scale is vary convenient for use in connection with the chlorine containers. The weight of the container is stamped on each cylinder and it is only necessary to subtract this weight from the total as indicated by the scale to tell at any instant how much chlorine there is in the container. By taking periodic readings, the operator is enabled to check the amount of gas as used each day against the amount as indicated or required by the flow of water. Chlorine tank pressure as shown on the chlorine pressure gauge is not an indication of the amount of chlorine remaining in the cylinder or cylinders. The pressure will remain reasonably constant until the container is practically empty.

SCHEDULE OF MAINTENANCE OPERATIONS

The following notes on maintenance are applicable to gas chlorinators.

Inspect for Leaks (Daily)

Examine chlorinator and all piping for chlorine or water leaks. All chlorine leaks are serious, because they increase rapidly in size and cause extensive corrosion and damage. Red discolouration means scale.

To locate chlorine leaks, hold mouth of unstoppered ammonia water bottle near all joints, valves and along piping; white fumes of ammonium chloride indicate a leak. Keep ammonia bottle tightly stoppered when not in use to prevent loss of strength.

Operate Chlorine Valves (Daily)

Open and close all chlorine valves to prevent threads on stem from becoming set in one position. Do not use force in closing a valve. Check stuffing boxes.

Check Gas System (Daily)

Check that all parts carrying chlorine gas are operating properly. See that metering devices, pressure-reducing and shut-off valves, tubing and so on function properly. Disassemble and clean where necessary, determining cause of fault.

Check Vacuum Relief (Daily)

Make sure assembly operates properly and relief hose line is not plugged. Insects may plug lines.

Clean Cabinet and Critical Working Parts (Weekly)

Thoroughtly clean chlorinator cabinet, glass parts, floats, metering devices, and other parts in which dirt might interfere with operations or make equipment unsightly. All unpainted metal parts should be coated with vaseline, preferably laid on with a brush, to prevent possible external corrosion.

Check Water System (Monthly)

Clean water strainers and check pressure-reducing valves for proper operation. See that float valves are properly controlling water levels and that leakage and splashing is at a minimum. See that water flowing to waste is not excessive and that water levels are kept at their proper elevations. See that ejectors have their original capacitites. If they do not, remove and clean with muriatic acid.

Disassemble or Operate Important Hard-rubber Threads, Valves and Parts (Quarterly)

Hard-rubber threads or parts on a chlorinator freeze or stick when not operated for long periods, causing breakage when parts are disassembled. To keep threads from freezing, operate all parts needed to keep chlorinator in service.

Caution: Use no tools on hard-rubber parts except for rare and careful use of a strap wrench. Tighten hard-rubber parts only fingertight. Before reassembling such parts, cover with graphite grease.

Examine Solution Tube (Annually)

Check tubing for abrasion that might cause leaks. Inspect tubing for kinks or for mineral deposits restricting discharge. Remove iron or manganese deposits from diffuser tube by adding ten percent solution of hexametaphosphate or septaphosphate to make-up water, at rate of 1 drop per minute. To add reagent, attach rubber hose to bottle containing treatment solution, and place pinch clamp on rubber hose. Invert bottle and adjust pinch clamp for proper feed rate.

Overhaul (Annually)

Remove chlorinator parts and clean thoroughly. Paint chlorinator cabinet inside and out with three coats of rust-resisting paint. Carefully examine each chlorinator part. Reassemble and check for proper operation.

1. The only safe liquids for cleaning chlorine lines are wood alcohol and carbon tetrachloride. After cleaning, allow it to evaporate to dryness. Ethyl alcohol or ether are converted by chlorine into solid waxy substances. Water combines with chlorine to form a highly corrosive substance.

2. Oil or grease react with chlorine to form a voluminous frothy substance. Therefore, they should not be used as lubricants at points where they may come into contact with chlorine.

3. Condensation forming on chlorine cylinder walls may corrode scales and other equipment around the cylinder. Guard against such damage by improved ventilation around the cylinder to keep surfaces dry. An electric fan may suffice. Do not apply direct heat to dry the cylinder.

4. It is dangerous to attempt to increase the rate of gas withdrawal by heating chlorine cylinders or containers above normal room temperature with hot water baths or other means. Inspect regularly to see that chlorine cylinders are not near steam, hot water lines, or other sources of heat.

5. Use a new lead gasket in connecting valve or tube and when replacing empty chlorine cylinders. Use only one lead gasket.

SOLUTION FEEDERS

Solution feeders may be non-positive or positive displacement. Non-positive displacement solution feeders include decanters, orifice rotameter and crystal solution types. Positive displacement feeders include the rotating dipper and proportional pumps.

A solution feeder is always preceded by a dissolving or a solution tank.

The following discussion will be directed mainly at hypochlorite feeding equipment since the increased use of more stable hypochlorites has led to the design of a large number of ingenious chemical feed devices. Such factors as viscosity, chemical attack and abrasion must be considered when choosing a pump for chemical service. It is not possible to cover all these factors and chemicals in this lecture. It is sufficient to say that a chemical pump which operates well on one chemical can be quite unsatisfactory on another and, therefore, you must check with the manufacturer before making any changes to chemical feed pumps.

The majority of these feeders take the form of a positive displacement solution pump, utilizing either a diaphragm or piston as the main pumping element. The amount of solution pumped can be varied by changing either the length of stroke, number of strokes per minute, or a combination of both.

Commercial hypochlorite feeders are generally operated either by electricity or water pressure. Further design features usually also provide for either manual or automatic operation. In manual operation the dosage must be changed by the operator, while automatic operation is usually accomplished by means of a displacement meter in the main pipeline, or by means of a small meter installed in a bypass around an orifice plate or venturi tube.

Although the initial investment in control equipment is lower, it is more expensive to use chlorine compounds as a source of chlorine than to use gaseous chlorine. Hypochlorites are widely used where the consumption of water is so small that the cost of chlorine is of little consequence.

SCHEDULE OF MAINTENANCE OPERATIONS

The following notes on maintenance operations are applicable to both pump-type and proportional-type solution feeders.

Check Operation (Daily)

Inspect sight-feed indicators to ensure that solution is being fed.

1. See that automatic controls start and stop properly.
2. Check sufficiency of prepared solution.
3. Check for leaks in piping joints and packing glands.

Clean Feeder (Weekly)

Remove and clean glass and plastic parts of sight-feed indicator. Remove white coating caused by hard water in hypochlorite solutions by soaking in 5 percent solution of muriatic acid.

1. Clean and flush solution tank or solid chemical dissolving compartment.
2. Clean screens and strainers on water lines.
3. Operate all shut-off and rate-control valves.

Overhaul Feeder (Annually)

1. Remove, inspect and replace all worn parts and packing.
2. Clean all orifice plates, needle valves, screen in water meter, etc.
3. Touch up all metal parts with paint.

DRY FEEDERS

There are two basic types of dry feeding mechanisms--volumetric and gravimetric.

Volumetric feeders are designed for volume displacement. Scales are not a part of volumetric feed mechanisms, although they may be provided for calibration of the equipment. Also, platform scales may be used to support the entire machine and its contents to provide a record of chemicals discharged. In this case, the scales do not control the rate of feed, but do permit a reasonable check on machine performance.

Change in bulk density or feeding characteristics of the chemical being handled directly affect the actual weight of the material delivered. Since volumetric feeders can measure only the volume displaced and not material weight, there is no provision for warning the operator if the chemical is not being fed. It is possible for volumetric equipment to operate mechanically without delivering chemical. Volumetric feeders usually require close attention from plant operators to ensure continuous operation at acceptable efficiency. They are used in small plants where rate of operation is relatively constant, regular performance checks of equipment operations can be made, and retention capacity of mixing and settling basins is sufficiently large to offset feed variations caused by changes in chemical bulk density or feeding characteristics. The potential accuracy of feed rate control with standard volumetric equipment is ±3-5 percent (by weight) under average conditions, but ± 10 percent deviations from preset rates may be anticipated with normal variations in chemical characteristics and operating attention.

Gravimetric feeders, which incorporate accurate weighing devices, are designed to feed dry chemicals continuously by weight. Because of their improved accuracy in controlling feed rate, wider feed range and their suitability for combination with recorders, totalizers and automatic controls, they are preferred over volumetric units. Generally, the rate of feed is independent of bulk density or flow characteristics of the chemical being fed, although materials having caking or flooding tendencies cause difficulty in regulation of feed. These units are designed so that when the feed rate has been preset, the feeder will maintain this rate of feed by weight control, within reasonable limits. The guaranteed accuracy of gravimetric feeders is ± 1 percent by weight.

TYPES OF VOLUMETRIC FEEDERS

Volumetric feeders may be sub-divided into three major types based on the principle of operation.

Oscillating Hopper and Tray Type

This is probably the most familiar type of chemical feeder in the volumetric field, In general, these feeders incorporate a motor driven oxcillating hopper which continuously discharges a ribbon of chemical from a feeder tray suspended beneath the hopper. Adjustments in rate of feed are made by varying the length of stroke; that is, the amplitude of the oxcillator of the hopper and/or the depth of the ribbon discharged from the tray.

Disc Type

This feeder incorporates a continuously revolving disc operating under a storage hopper. The material is then discharged at this portion of the disc. Feed adjustments to this type of feeder are made by varying the gate opening which varies the depth of material carried by the disc and/or varying the speed of rotation of the disc. This feeder is very suitable for feeding at low feed rates. In all these units, delivery rates are regulated by clutch mechanisms, adjustable gears, or cams which can be manually adjusted during service to change speed of rotation, ribbon thickness, or feed blade setting.

Rotary Type

This feeder consists of a continuously rotating drum with a series of feed pockets. The drum rotates beneath a storage hopper and discharges the volume of the individual pockets as each pocket rotates out from under the storage hopper. Feed adjustment of this machine is normally made by varying the speed of rotation of the rotor. Feeders of this type are normally used for feeding materials which have a tendency to arch and flood since the rotary mechanism is positive protection against flooding of chemicals. This type of feeder has been widely used for feeding activated carbon. These units can be combined with rate-setting devices to permit their application to automatic pH control or variable flow systems.

TYPES OF GRAVIMETRIC FEEDERS

Gravimetric feeders are manufactured in two basic types, the loss-in-weight and belt gravimetric units. Regardless of type, every gravimetric feeder must include a weight sensing element, a feed mechanism, and a controller. The scale and feeding mechanisms in all units are reasonably standard. However, the method and complexity of control mechanisms vary widely.

Loss-in-Weight Type

In this type of feeder, the entire feeder hopper is suspended on a scale system. The feeder then releases or feeds material from the feeder hopper so that the loss of weight of material in the hopper is controlled to equal whatever feed rate has been set to the machine. The feed rate is determined by the rate at which a mechanically-driven lead screw retracts the counterweight on the scale beam. Changes in feed rate are made by varying this speed of retraction. Loss-in-weight feeders never need to be calibrated even on initial start up, since the scale system itself is an accurate weighing device.

Belt Type

In a typical belt gravimetric feeder, dry chemical enters the feeder at the top through a chute or hopper and passes to the feed mechanism. Here it is fed to a weigh belt supported on a scale. This small moving belt delivers the dry chemical to the feeder outlet or dissolving tank. The scale controls the feeding mechanism so as to maintain a uniform weight of chemical on the weigh belt, regardless of changes in the bulk density. Belt gravimetric feeders must be calibrated by catching samples on initial installation. Once calibrated however, a belt feeder need not be calibrated again since the initial calibration data will continue to hold true.

Feed rate adjustments may be made in two ways:

1. By adjusting the acale beam counterweight to increase or decrease weight on the weigh belt, while allowing the belt to run at a constant speed.
2. By varying belt speed while maintaining constant chemical weight on the weigh belt. The scale beam is combined with rate control devices such as vibrators, to regulate operation of the feed tray which delivers chemical to the weigh belt. As an alternative, control may be obtained by variations in feed gate opening to maintain a preset feed rate from the weigh belt.

SCHEDULE OF MAINTENANCE OPERATIONS

The following notes are applicable to volumetric dry feeders:

Clean and Inspect (Daily)

Clean feeder, feeder mechanism, and feeder surroundings. Remove spilled chemical and chemical-dust accumulations with vacuum cleaner or brush. Look for oil drips, wiring defects, and deterioration. Observe general performance of feeder. Note and investigate unusual noises. See that orifice, knife edges, scrapers, shakers, and openings are free of chemical accumulations. Probe solution tank for sediment or undissolved chemical and make necessary corrections. Be sure that hopper fills are made without chemical spillage on working parts of feeder. If chemical feeder is out of service, see that feeder is empty of chemical and that condensation is not causing deterioration.

Inspect for Loose Bolts and Cracks (Weekly)

Carefully wipe all parts of feeder. Inspect for loose bolts, cracks, defective parts, and leaks.

Test Calibration (Monthly)

Make several calibration tests, using range of feed in which chemical feeder operates most frequently, to check accuracy of rate setting devices, charts, or tables.

1. Test with feeder not on scale. With chemical feeder off scale and delivering uniformly after a change in rate of feed, catch delivery in pan for a known period of time. Weigh material caught and calculate feed in pounds per hour. Compare with indicated rate setting on chart. Be careful and accurate in timing, weighing and collecting material. Perform each test several times to check results.

2. Test with feeder on scale. With feeder on weighing scale, check rate of feed by stopping feeder, balancing scales, and then running feeder for a known period of time. Stop feeder and rebalance scale. Subtract this reading from previous scale reading to determine amount of chemical that passed through hopper in the given time.

Overhaul (Annually)

Overhaul chemical feeder, clean and paint interior and exterior. Clean and repair solution and make-up tanks. Service drive-mechanism bearings and other machanical parts.

The following notes on maintenance are applicable to gravimetric belt type dry feeders, and also the loss-in-weight type except for the description of the delivery test.

Clean, Check and Test Balance (Daily)

Clean feeder, feeder mechanism, and surroundings. Empty feed belt, clean off accumulations, and test scale balance with zero load. Make necessary adjustments to correct tare-weight balance. Check for mechanical and electrical defects and for proper operation. Look for oil drips and wiring defects. Observe general performance and investigate unusual noises. Make sure chemical is not accumulating on inner roll of belt or adhering to belt in a manner which may cause too high a tension or tare. Check solution tank and the feeder out of service as pointed out previously for volumetric feeders.

Inspect for Loose-Bolts and Defective Parts (Weekly)

Carefully wipe all parts of feeder inspceting for loose bolts, leaks, defective parts, and so on. Check belt tension.

Make Delivery Test (Monthly)

To locate feeder abnormalities, test delivery of feeder to see that its actual output is equal to weight indication totalizer or integration device.

1. Clean belt and feeder and then balance scale. Return feeder to service and operate until chemical forms an even, uniform layer on feeder belt and scale remains in close balance. See that poise on scale beam indicates proper load on belt.

2. Stop motor. See that scale with its load of material moves freely and is in exact balance. If it is not, add or remove material from rear end of load on belt until exact balance is obtained.

3. Disengage or stop operation of mechanism which feeds chemical to belt. Read belt revolution counter or weight integrator. Then operate feeder belt until

counter or weight integrator indicates that exactly a predetermined number of pounds of chemical, about two-thirds of belt loading, have been fed. Stop feeder instantly by turning off motor switch.

4. Again see that scale can move freely and then move poise to bring scale back to exact balance. Note scale reading. The difference between this scale reading and initial scale reading gives exact weight of material which has been delivered.

5. If this reading does not coincide with number of pounds as shown by revolution counter, adjust as follows:

   (a) If actual delivery as shown by front scale beam is greater than indicated by revolution counter, move poise on scale beam to a lower figure so belt loading is less, then repeat test.

   (b) If actual delivery is less than indicated by revolution counter, move scale poise to higher reading on scale beam so belt loading is greater and repeat test.

6. Continue testing until a belt loading is found which results in delivery of material corresponding exactly with reading of revolution counter. When this location is determined, set and change poise on scale beam at this position, and record setting for future reference. Thereafter, when feeding same sort of material, use same belt loading. Recalibrate when using a different type of material which has a different degree of slope at which material falls off front end of feeder belt.

   NOTE: For certain other belt type feeders, a delivery test can only be made by catching delivery during an exact test period and weighing the catch. Actual delivery rate of feeder can be calculated from these data.

Overhaul Feeder (Annually)

Remove feeder-belt assembly, motors, belts, and the like where practical and overhaul feeder completely. Clean and paint entire structure. Clean scales, and edges and test for sensitivity. Lubricate all mechanical parts, and make necessary repairs.

PREPARATION OF CHARTS AND GRAPHS FOR WATER WORKS USE

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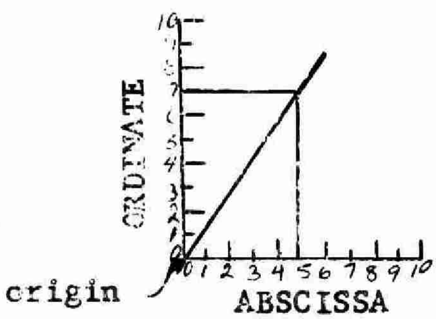
Charts and graphs play an important dual role in the operation of the water treatment plant. The first is a saving in time and effort due to minor repetitious calculations. The second and more important is that they offer rapid and accurate answers such as settings on chemical feed machines for correct feed rates, values of discharges at various pressure or heads from a pump curve and in fact the interpolation for any values in a continuously variable function.

A chart is an orderly setting down or tabulation of sets of similar values or results.

A graph is simply the pictorial representation of the chart or tabulated data.

Before going into the construction of graphs for practical purposes, it is necessary to know and understand the basic terminology used in conjunction with graphs and how to read values from them.

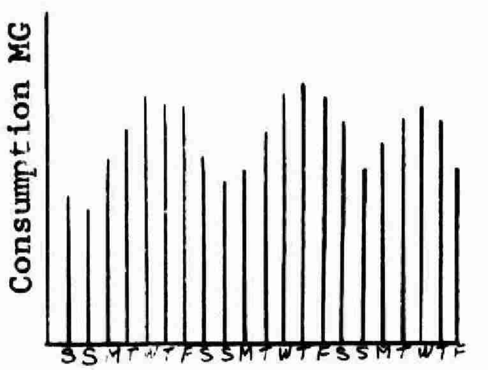
(See Figure 1)



The horizontal and vertical lines are the axes of the graph and are called abscissa and ordinate axis respectively. Arbitrary values are assigned to each axis such as gallons per minute, pounds per square inch, parts per million etc. and the axis is divided into increments. The distance used between increments is very important since the smaller the distance used between them, the less is the degree of accuracy to which the graph can be read. Values can be determined from the graph by constrcting lines parallel to the axes and reading the values where these lines intersect the axes. If you follow the dotted lines from the point P in figure 1, the co-ordinates or values of the point P are read as the abscissa and ordinate and are equal to five and seven respectively.

In addition to the line graph just explained there are a number of other types of graphs but let us consider one other, the bar graph. Unlike the line graph which represents pictorially the changes in a continuously varying function the bar graph represents specific individual values of the same event, which occur in succession and which are not governed by any mathematical law.

For example we can plot a graph of the quantity of water used by a town against each calendar day in the form of a bar graph as shown in Figure 2. Each vertical line represents the total flow for one day and in itself is a complete value of one specific event. It is important to remember that at the very moment at which a new day starts, the flow is zero and increases to a maximum at the end of the day. Therefore by joining up all the points by a line graph would mean that the flow varies smoothly from one daily flow to another which of course is not true.



Since it would be impossible to present all the many ways in which a graph could be used, only a few methods will be illustrated.

The first of these is the calibration and construction of the calibration curve for a gravimetric dry chemical feeder. This example shows the construction and use of a graph involving two variables which are the rate setting device reading and the actual rate of discharge from the feeder. The equipment required for the calibration is a scale, a container to collect from the discharge and of the feeder and a timing device. The method of calibration is as follows:

If the scale on the rate setting device reads from 0 to 50 pounds per hour, select five scale readings say 10, 20, 30, 40 and 50 pounds per hour respectively. Collect a sample from the discharge of the feeder over a measured period of time for each scale setting. The period of time should be varied so that a large enough sample is obtained thus minimizing possible errors. Weigh each sample and convert the respective weights and times into pounds per hour. The results should be tabulated in a chart as shown in Figure 3.

Rate Setting (lbs./hr.)	Time (Mins.)	Weight (lbs.)	Actual Rate (lbs./hr.)
10	6	1.10	11
20	5	1.83	22
30	3	1.65	33
40	2	1.46	44
50	1	0.91	55

Figure 3

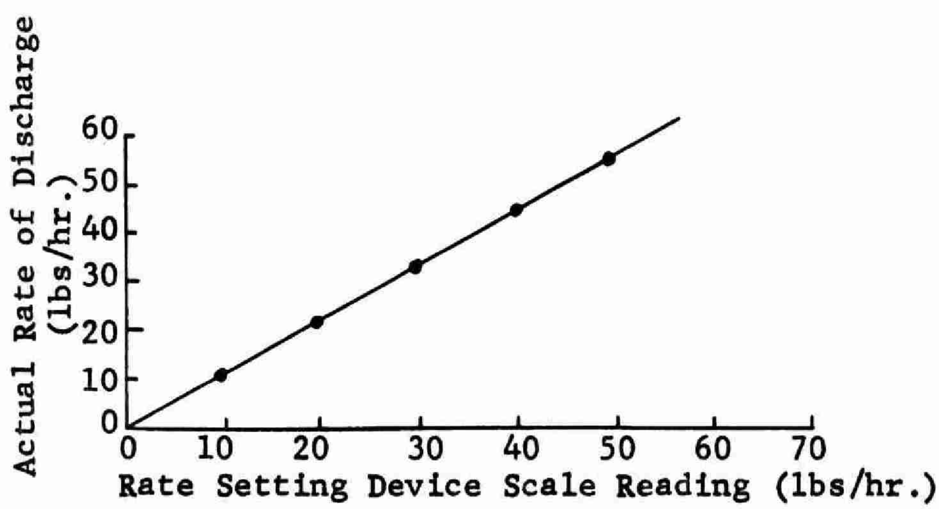


Figure 4

The actual discharge rates with the scale readings are then plotted as shown in Figure 4. It is now a simple matter to determine at which reading the rate setting device should be set to give the required rate of discharge.

The next example will show the use of a graph involving three variables. Consider the case of a solution feeder which uses the flow of water through it to power the pump. The three variables are the flow of water, the control knob setting and the amount of solution pumped. The equipment required for calibration is a graduated cylinder for collecting and measuring the volume of solution discharged, a flow measuring device and a timing device. Allow the feeder to run for a few minutes before starting the sampling. Set the control knob at ¼ open, read the rate of flow

of water and collect a sample during a measured period of time. Remember to record the various readings in a chart as shown in Figure 5. Vary the flow rate through the complete range of the instrument then repeat the same procedure for ½ open, 3/4 open and full open.

ONE QUARTER OPEN		ONE HALF OPEN		THREE QUARTERS OPEN		FULL OPEN	
Solution (ml/min.)	Water (gpm)	Solution (ml/min.)	Water (gpm)	Solution (ml/min.)	Water (gpm)	Solution (ml/min.)	Water (gpm)
0.5	2	1.2	2	1.7	2	1.9	2
1.9	4	2.4	4	3.7	4	3.9	4
3	8	5.5	8	7.6	8	8.5	8
4.5	12	8.2	12	11.5	12	12.8	12
3.9	16	11.9	16	15.9	16	17.6	16
4.0	20	15.2	20	21.0	20	23.5	20

Figure 5

Now plot the information in the chart on a graph (Figure 6.) The procedure is the same as for the previous example except that a curve is constructed for each control knob setting.

The graph is constructed this way because each curve represents one constant value and two variables while the whole graph represents the three variables. Therefore only two of the variables need to be known to determine the value of the third. This is shown by the dotted line on the graph.

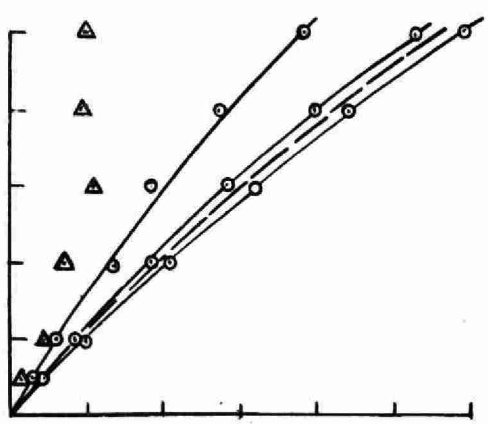


Figure 6

It may be necessary to operate the machine at some intermediate setting e.g. 7/8 open and the curve corresponding to this setting can be estimated by merely dividing the distance between the 3/4 open curve and the full open curve in half. This is shown as the dotted curve labelled "estimated 7/8 open".

Both of the previous examples show the use of graphs for the purpose of accuracy. The next example will show how a graph can save time and effort due to repetitious calculation. For this example a chlorine gas feeder will be used and a graph will be made to determine the chlorine dosage in parts per million (ppm) from the pounds per day of chlorine feed and the daily rate of water flow. The equation or calculation used to construct the graph is:

$$\frac{\text{chlorine feed (lb/day)} \times 1{,}000{,}000}{\text{water flow rate (gal/day)} \times 10\ \text{(lb/gal)}} = \underline{\underline{\text{chlorine dosage (ppm)}}}$$

or

$$\frac{\text{cl feed (lb/day)}}{10 \times \text{water flow (MGD)}} = \underline{\underline{\text{Cl dosage ppm}}} \quad \text{--------------(1)}$$

Sample Calculation

Chlorine feed = 12 lbs/day
Water flow = 2 MGD.

$$\text{Chlorine dosage} = \frac{12}{2 \times 10} = \underline{0.6\ \text{ppm}}$$

The procedure for the construction of this graph is similar to that used for the second example ie. for every flow rate used, a series of chlorine feed rates and concentrations are calculated, giving the graph shown in Figure 7. It is useful to note that Figures 6 and 7 are similar except that the individual lines in Figure 7 are straight lines. This fact can be used to advantage since a closer look at equation (1) shows that all of the individual lines or parameters for each water flow rate, pass through the origin (or intersection of the axes). This means that only one calculation is required for each water flow rate assumed, in order to establish its curve. This eliminates the need for a tabulation of calculated values as previously required. The interpolation of a parameter line for a flow rate not calculated is obtained in a similar manner as previously indicated for example two.

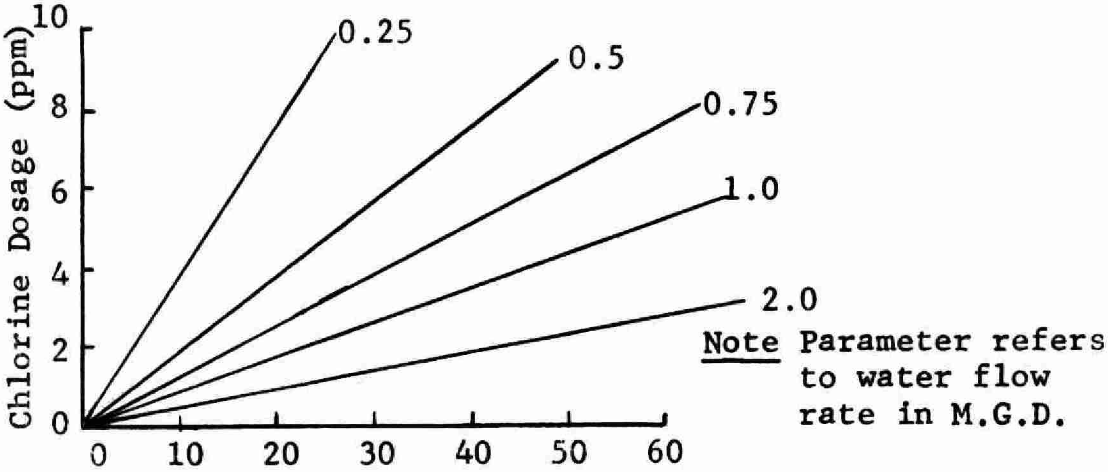


Figure 7

Another phase of water works operation which can be usefully studied in graph form is the fluctuation of water demand throughout the day and also the variation of total daily flow.

In the case of daily fluctuation of flow the graph is prepared by plotting the demand at various times throughout the day. Where the water works has the circular flow charts or strip charts it is easy to read off the demand values throughout the day. Where such charts are not available it is necessary to take flow meter readings every hour or two hours.

A typical graph of hourly demand throughout the day would look like figure 8.

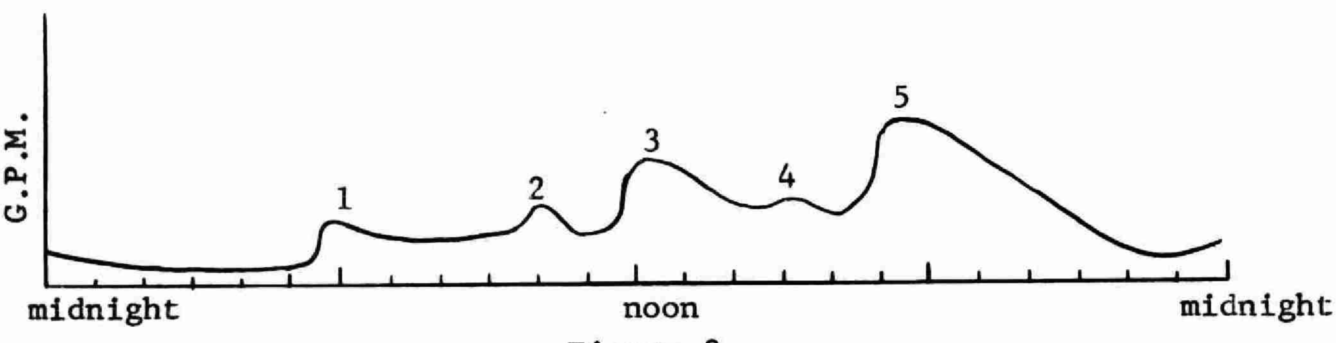


Figure 8

Note that the flucutations numbered show demand increases caused by:

(1) breakfast
(2) school recess
(3) lunch
(4) afternoon recess
(5) supper

If a graph like this is made for each day of the week, it will be noted that considerable differences occur which can be explained, for example by "Washday Monday", low week industrial use, fire, water main or hydrant flushing, lawn watering etc. By establishing an average pattern for your plant you will immediately be able to recognize unusual occurrences in the system, like breaks.

Preparing a graph which shows the total daily flow for each day is valuable in providing pictorial records of change and on a long term basis will give a good indication of the trend of water consumption. The typical graph in Figure 9 is condensed and shows the total flows for each month over a two year period.

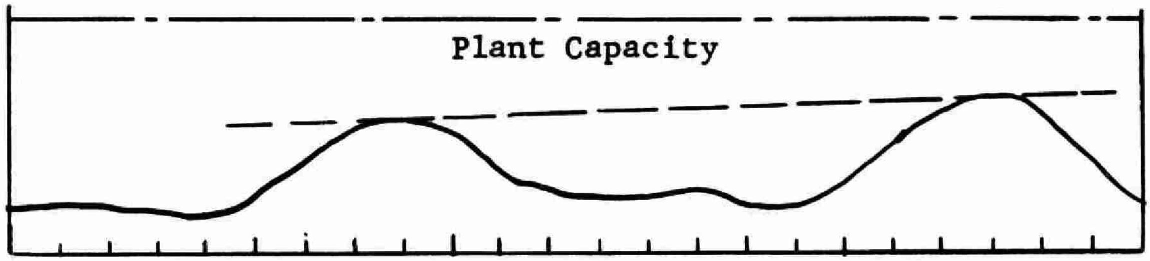
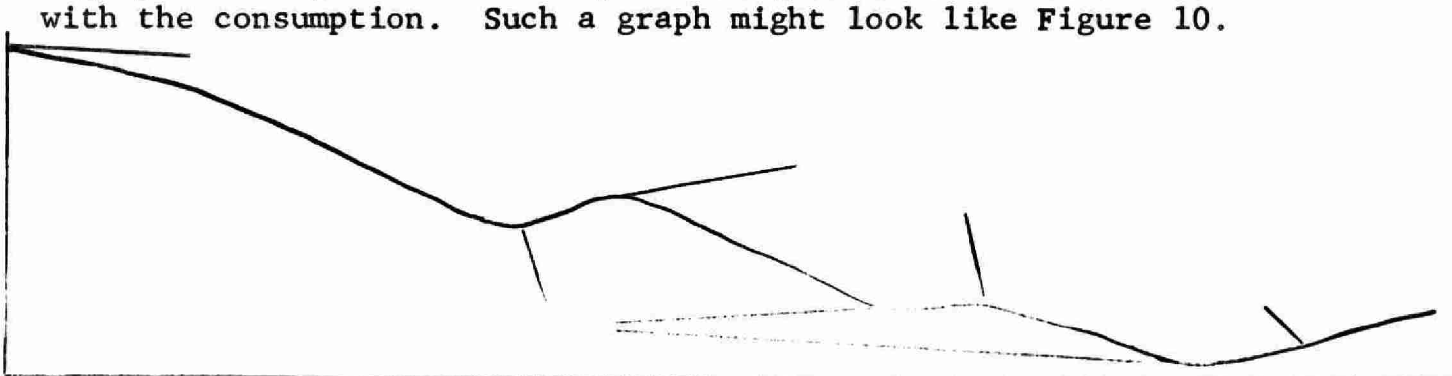


Figure 9

It is well to remember that a two year plot will not be sufficiently accurate to predict a proper trend, however an indication will be given by comparison of the general increase in consumption at equivalent times of the year. A more valid prediction could be made with say five or six annual peaks when it would be possible to take the "best line" of fit of these points. At best we could only estimate when consumption would equal production, however, it is valuable to keep a close watch on the overall change to avoid a sudden realization the plant cannot produce the volume required.

Finally it is interesting to take a look at the economics of the treatment where cost figures are available. A graph can be plotted showing the total operating cost for each month and from this information it is possible to prepare a graph showing how the cost per 1000 gallons of water varies with the consumption. Such a graph might look like Figure 10.



Consumption MGD

Figure 10

It is suggested that the cost per 1000 gallons will decrease with increasing consumption to point of plant capacity. A necessary expansion in equipment and or staff will tend to increase the unit cost which will again reduce to the new plant capacity. Obviously there will be a final optimum economy which cannot be bettered.

It is impossible to illustrate all the ways in which graphs may be constructed and used but with a fair knowledge of the basic principles many more problems will be recognized which can be solved or at least more clearly understood by the use of graphs.

REMOVAL OF HYDROGEN SULPHIDE

FROM MUNICIPAL WATER SUPPLIES

by A. Oda, P.Eng

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Hydrogen sulphide is a colourless gas that has an offensive odour resembling "rotten eggs". This substance is sometimes found in mineral waters derived from some wells and so-called sulphur springs located in certain regions throughout Ontario. The presence of hydrogen sulphide in any public water supply, even in trace quantities, is highly undesirable as it imparts objectionable tastes and odours to the water and may lead to other nuisance problems in the distribution system. Therefore, hydrogen sulphide must be completely eliminated from the water before it reaches the consumer.

PROPERTIES OF HYDROGEN SULPHIDE

Chemical Formula - H_2S

Physical

Colourless.
Odour of rotten eggs.
Gaseous substance which is slightly heavier than air. 1 liter weighs 1.54 gm.
Moderately soluble in water.
Behaves like most normal gases; that is, its solubility decreases if the temperature of the water is increased.

Chemical

Burns with a blue flame.
Very toxic in air.
Maximum safe concentration in air is estimated to be about 13 ppm.
Reacts with metals to form sulphides.
Enhances the corrosive nature of water even in very small concentrations.

Where is H_2S found?

Hydrogen sulphide is generally more common to well supplies than to surface supplies. It is likely to be found in water obtained from wells located in Boulder clay, limestone-gypsum areas or near "sour gas" producing oil fields. It may also be found in highly mineralized ground waters, particularly those with relatively high sulphate content. Wells located in the vicinity of so-called "sulphur springs" and some mine fields may yield waters with considerable amounts of hydrogen sulphide.

How is H_2S formed?

Hydrogen sulphide can be produced either chemically or by the action of anaerobic bacteria on certain substances present in the water. In well supplies, occasionally in some surface water supplies, the waters may be contaminated with alkaline or metallic sulphides as a result of deterioration of organic substances or from miscellaneous sources of industrial pollution. Under these conditions, carbon dioxide dissolved in the water will react with these sulphides and form hydrogen sulphide.

In most water supplies, hydrogen sulphide is usually present in trace quantities. It is formed from the decomposition of certain organic substances and sulphates under anaerobic conditions. Two groups of bacteria are responsible for the production of hydrogen sulphide:

(a) Sulphur Bacteria

These organisms are found in mineral sulphur springs and waters polluted with sewage. They are capable of breaking down organic substances especially those containing sulphur and proteins and forming hydrogen sulphide in the absence of oxygen.

(b) Sulphate-reducing bacteria

These organisms are capable of converting inorganic sulphates and sulphur compounds into hydrogen sulphide.

What are some of the problems associated with H_2S?

(1) Hydrogen sulphide as gas is deadly and reacts in the same way as carbon monoxide and hydrogen cyanide. Maximum safe concentration in air is estimated to be about 13 ppm. However, in water, it is not considered to be as toxic. Waters containing hydrogen sulphide are often used for health drinks and also for bathing purposes at health spas.

(2) Trace quantities of hydrogen sulphide cause objectionable tastes and odours in potable water supplies. When present in concentrations over 1 ppm, this odour becomes objectionable in water. Some persons may even detect its presence in concentrations as low as 0.35 ppm. The following table* gives the recommended limits suggested for the concentration of hydrogen sulphide in water used for various industrial purposes:

Industrial Use	Recommended Limit in ppm
Baking	0.2
Boiler Feedwater	
0 to 150 psi	5
150 to 250 psi	3
over 250 psi	0
Brewing	0.2
Carbonated Beverages	0.0 to 0.2
Confectionary	0.2
Cooling Water	5.0
Food Canning and Freezing	1.0

(3) Hydrogen sulphide increases the corrosive character of water. This, in turn, may affect the water quality and cause discolorations and staining problems in the distribution system.

(4) Hydrogen sulphide in excess quantities will attack various metals and other materials used in the manufacture of water mains and plumbing fixtures. It reacts with iron and

* McKee, J.E. and Wolf, H.W., WATER QUALITY CRITERIA, 2nd. Edition, State Water Quality Control Board, California Publication, No. 3-A, 1963.

steel in water pipes to form suspensions of iron sulphide which are responsible for "black" water problems. As a result of sulphide corrosion, water pipes may become badly clogged.

(5) It has been reported that in some instances, small concentrations of hydrogen sulphide in water have damaged greensand zeolites in iron removal plants so that they can no longer be reconditioned.

(6) Hydrogen sulphide may react or interfere with corrosion inhibitors thus increasing the dosages of these chemicals. In some instances, the cost of corrosion protection becomes prohibitive.

METHODS OF REMOVAL

There are several methods of treatment that could be used for the removal of sulphides in water supplies. Since sulphides may be present in the form of both metallic sulphide and gaseous hydrogen sulphide, it may be necessary to utilize physical and chemical processes in order to achieve complete removal.

If a water supply contains relatively high concentrations of sulphides, it is more practical to consider some form of aeration as a part of the treatment process. However, not all of the sulphides can be removed by aeration alone. Therefore, in order to remove the last remaining traces of sulphide, the water is usually treated with some chemicals after aeration.

Aeration

In the aeration process, hydrogen sulphide dissolved in the water is released as a gas and then removed. Also, a portion of the sulphides may be eliminated by oxidation into free sulphur upon contact with oxygen.

Aeration is primarily a mechanical process in which the water is brought into intimate contact with air. Two general methods of aeration are employed. In one method, water,

in small droplets, is allowed to fall through the air such as in a coke tray (Figure 1) or an aerator using natural ventilation. This type of aeration can be accomplished by using various cascading and forced draft type aerators (Figure 2). In large waterworks, this method of aeration is most commonly used.

The second method of aeration is known as the air diffusion method. Air is bubbled up through a solid body of water by means of diffusers. In smaller waterworks, a hydropneumatic tank is used. This is a pressurized tank in which compressed air is introduced to the water through a nozzle or a grid system located at the bottom of the tank. Hydrogen sulphide gas released from the water along with excess air is expelled from the tank through the air relief valves.

Aeration with pH Reduction

A complete removal of hydrogen sulphide from water is not readily obtained by aeration alone. At higher pH values, sulphides are present in the water chiefly as alkaline sulphide and therefore cannot be removed by aeration alone. Data in the table * below show the relationship of pH and percentages of total sulphides available as hydrogen sulphide.

PERCENTAGE OF TOTAL SULPHIDE PRESENT AS H_2S

pH	Percent H_2S
5.0	98
5.4	95
6.0	83
6.5	61
7.0	33
7.5	14
8.0	4.8
9.0	0.5

* Pomeroy, Richard, Hydrogen Sulfide in Sewage, Sewage Works Journal, Vol. 13, No. 3, p. 498, (May, 1961)

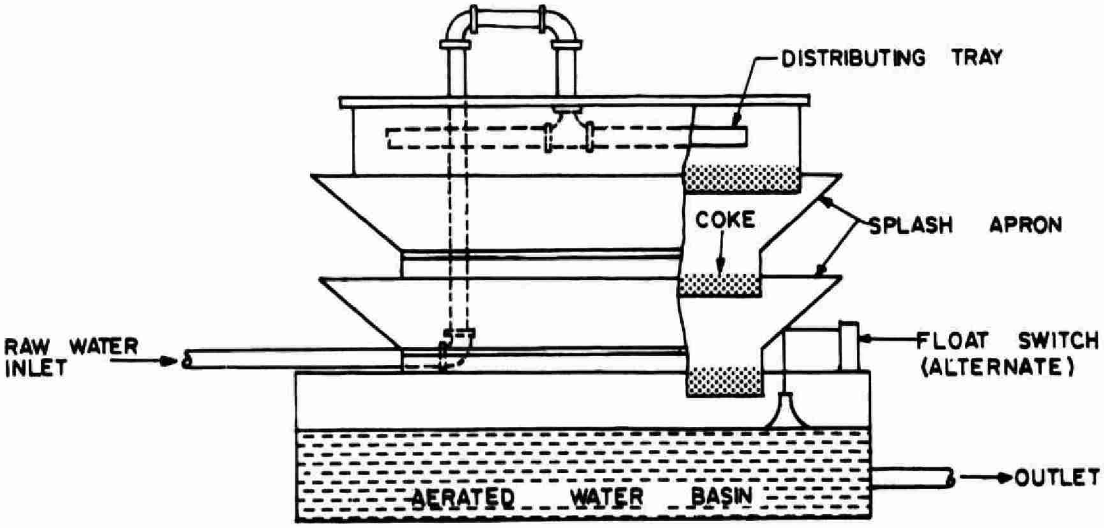

FIGURE 1

COKE TRAY AERATOR (Courtesy of Permutit Co.)

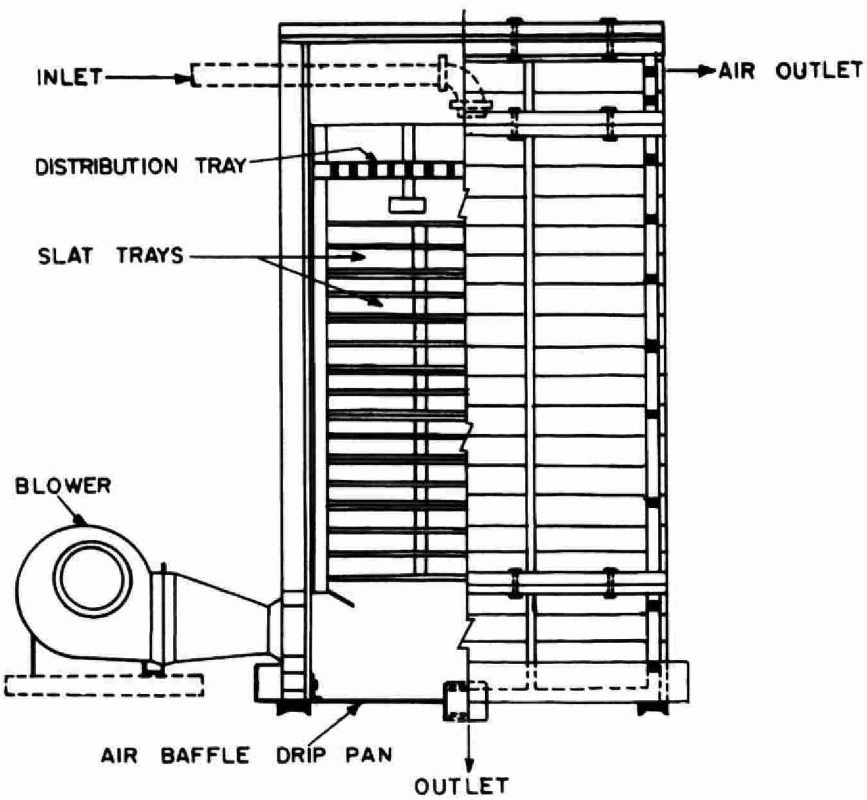

FIGURE 2

FORCED - DRAFT AERATOR (Courtesy of Infilco Co.)

These data show that a greater percentage of total sulphide is present as gaseous H_2S at lower pH values. Therefore, by reducing the pH of the water to the range of pH 4 to 5, nearly all of the sulphides can be converted into a gaseous form which is more effectively removed by aeration.

In recent years, flue gases have been used for the treatment of sulphurous waters. These gases contain about 13% carbon dioxide, which will reduce the pH value of the water sufficiently to liberate hydrogen sulphide. The quantity of gas required will depend upon the alkalinity of the water supply being treated.

A special type of equipment known as a hydrogen sulphide degasifier is available for this purpose. In consists of a double stack, which is essentially two forced draft aerators placed one on top of the other, with a water seal separating the upper carbonating chamber from the lower aeration chamber. The flue gas is introduced at the bottom of the upper chamber and mixed countercurrently with the falling droplets of influent water. The carbon dioxide in the flue gas reduces the pH of the water and this, in turn, converts the sulphides into hydrogen sulphide. The lower section is similar in design to the carbonating chamber. Here, the air moving countercurrently against the downward flow of water, provides additional scrubbing for the removal of carbon dioxide and any residual hydrogen sulphide in the water.

Reduction in pH of the water may also be obtained by feeding mineral acid prior to aeration. The feed of acid can be controlled to obtain the desired pH reduction. A major disadvantage of this method of treatment is that some adjustment must be made in the pH of the water after treatment.

By combining pH reduction with aeration, the size of the forced draft aerator can be reduced considerably with a more efficient removal of hydrogen sulphide.

With this method, some precipitation of colloidal or free sulphur can be expected, especially if the water supply contains a high level of sulphides. In order to provide water of good clarity, further treatment by means of coagulation and filtration may be necessary.

Chlorination

Although it is possible to reduce hydrogen sulphide to a very low level by means of aeration and aeration with pH reduction, these methods will not eliminate it completely. In some water supplies, hydrogen sulphide even in trace quantities, is undesirable because it will result in objectionable tastes and odours and increase the corrosive characteristics of the water. Therefore, it is necessary to employ chemical methods in order to remove all of the remaining traces of hydrogen sulphide.

Complete removal of hydrogen sulphide from water can be best accomplished by means of chlorination or by a combination of aeration and chlorination.

The reaction between chlorine and hydrogen sulphide can be represented by the following equations:

$$H_2S + Cl_2 = 2\,HCl + S \qquad (1)$$

hydrogen sulphide + chlorine = hydrochloric acid + sulphur

$$H_2S + 4Cl_2 + 4H_2O = H_2SO_4 + 8\,HCl \qquad (2)$$

hydrogen sulphide + chlorine + water = sulphuric acid + hydrochloric acid

In the first reaction represented by equation (1), hydrogen sulphide is oxidized to free sulphur by chlorine. Theoretically, 2.1 ppm of chlorine are needed to remove 1 ppm of hydrogen sulphide. The sulphur produced is in the form of a fine colloidal precipitate which may affect the clarity of water. In addition, it may be reverted back to hydrogen sulphide by the action of certain micro-organisms in the distribution system. Therefore, the precipitated sulphur should be removed by coagulation and filtration, especially if the water contains fairly high concentrations of hydrogen sulphide.

Equation (2) shows the result of a reaction using larger amounts of chlorine to oxidize hydrogen sulphide. The latter is oxidized further to sulphuric acid without any

precipitation of sulphur. In this reaction, theoretically, 8.4 ppm of chlorine are required to remove each ppm of hydrogen sulphide. It can be seen that larger quantities of chlorine are needed for a complete removal of hydrogen sulphide and therefore, this would help to increase the cost of treatment. Consequently, for water supplies with high concentrations of sulphide, a more economical method is to remove as much hydrogen sulphide as possible by aeration with reduced pH and then utilize chlorination for complete removal.

Anion Exchange

Anion exchange resins have been developed which are applicable for the removal of hydrogen sulphide from water supplies. These are highly basic resins which will adsorb sulphide, sulphate and other ions. They can easily be regenerated with salts and/or sodium bicarbonate depending upon the pH of the water. This reaction can be illustrated as follows:

$$R_4N.OH + H_2S = R_4N.HS + H_2O$$

$$\text{Basic exchange resin} + \text{hydrogen sulphide} = \text{sulphide resin} + \text{water}$$

"R" represents the resin matrix

At the present time, the application of these resins for hydrogen sulphide removal has been limited to domestic uses because they are only capable of handling low capacity and low flow rates. The water to be treated must be iron free and preferably, low in hardness.

The equipment is similar in design to a pressure type water softener containing ion exchange materials. One of its main advantages is that this equipment can be easily inserted into a water supply without breaking the line pressure and therefore no oxygen needed to be added to the water for hydrogen sulphide removal. A low cost regenerant can be used. Another feature is that it is also possible in some cases to convert some of the existing zeolite softeners to perform both functions of water softening and hydrogen sulphide removal in one operation.

ANALYSIS FOR SULPHIDES

In most water supplies, hydrogen sulphide is usually present in amounts less than one ppm and more likely to be in the range of a few tenths or hundredths of one ppm. In order to obtain meaningful data, it is necessary to analyze the water at the time of sampling. In some instances, it is possible to "fix" the sample for sulphides at the source and then bring it back to the laboratory for analysis.

The fixing reagents consists of 2N zinc acetate solution (220 gm $Zn(C_2H_3O_2)\cdot 2H_2O$ dissolved in 1 litre of distilled water). 2 ml of this solution per litre is placed in the collecting bottle. Samples must be taken with a minimum of aeration because any sulphides present may be volatilized by aeration or destroyed by oxidation upon contact with the oxygen.

Any samples, not preserved with zinc acetate, must be analyzed for sulphides within 3 minutes of the time of sampling.

For the on-the-spot tests, small test kits utilizing colorimetric methods are available. These provide reasonably good analyses for low concentrations of hydrogen sulphide.

SUMMARY

The general methods for the removal of hydrogen sulphide in water supplies may involve one or a combination of the following treatment practices:

(a) aeration
(b) aeration with pH adjustment
(c) chemical treatment with one of the following:

 (i) chlorination
 (ii) potassium permanganate
 (iii) ozone

(d) ion exchange with strongly basic anion resins

The method selected for a particular water supply will be determined by various factors such as:

(a) total sulphide
(b) chemical quality of the raw water
(c) ultimate use of the water
(d) desired level of sulphide in the treated water
(e) availability of treatment facilities

It should be remembered that these methods of treatment will only remove or reduce sulphides to acceptable levels. In some instances, further treatment involving coagulation and filtration may be required to produce water of good clarity and acceptable quality.

The importance of good disinfection practices cannot be overemphasized in helping to minimize the nuisance problems experienced in water supplies affected by hydrogen sulphide.

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LABORATORY DEMONSTRATIONS

FOR

FLUORIDES ANALYSES

JAR TEST

TURBIDITY TESTS

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I FLUORIDE ANALYSES

The most popular methods of fluoride determination all depend on the reaction between the fluoride ion and a chemical dye. The ion reacts with the dye (a compound of the metal zirconium) to form a colourless compound, i.e. the colour is bleached out in proportion to the concentration of fluoride present. Since this is a progressive reaction in most tests, it is very important that the comparator be read at a specific time from the beginning of the reaction. When the test is conducted using a direct reading (meter-type) instrument, the test is modified so that the colour reaction is instantaneous.

All glassware and sampling bottles must be kept very clean, and care should be taken that this equipment is not stored or used in an area where fluoride dust will be deposited, since extremely small quantities of the compound will create substantial errors in the analyses. Sample bottles preferably should be polyethylene, although glass would be suitable if care is taken to see that no high fluoride samples are stored in them.

II JAR TEST

Introduction

The jar tester or multiple stirrer is exactly what its name implies--a device for stirring the contents of several containers at once. Generally, the jar tester has six paddles driven by an electric motor. There is an infinitely variable speed control to give speeds from 0 to 100 rpm and a tachometer to indicate paddle speed.

This device is used to simulate conditions in the mixing and flocculating sections of a water plant. That is, each jar or container represents a mixer-flocculator and thus six different experiments may be conducted simultaneously.

It has been established by experience that in chemical coagulation of water, the order, concentrations and types of chemicals used to coagulate a given type of water may all be of importance to the efficiency of the treatment process. It is easy to visualize that, if there are three chemicals of interest to the operator and each one has a range of ten concentrations in which it might be useful, then, if the order in which the chemicals are added also affects the coagulation process, he must conduct 1000 jar tests to investigate all possible combinations. The jar tester simply makes it possible to conduct six tests at a time.

Operating Considerations

To be useful to the plant operator, the jar tester must approximate as closely as possible the process in the plant itself, i.e. rapid mix, slow mix (flocculation) and settling must be carried out for the same time intervals and at approximately the same rate of agitation. Rate of agitation must not be confused with revolutions per minute. Twenty rpm in a one litre beaker under a jar tester may produce the same agitation as five oscillations per minute of a walking beam flocculator in an actual plant.

The "standard" jar test (if such can be said to exist) consists of a 1-2 minute high speed mix at 80-100 rpm, 20-30 minute slow mix at 20-25 rpm and 30-60 minute settling. This test can be useful when sampling a water supply which will be the source for a treatment plant yet to be built, since the plant can be tailored to these conditions. When one is attempting to adapt a jar test procedure to an existing plant, the only method which will give good results is trial and error aided by visual observation of the plant itself. When the jar test procedure approximates the operation of the plant, you have an extremely useful tool to assist you in maintaining a constant effluent quality under varying raw water conditions. Changes in chemical dosages can be quickly evaluated in the tester and their success or failure determined before trying them in the plant.

Generally, a jar tester will give results that only approximately parallel the plant. That is, if a given dosage of chemical gives certain results in the tester, somewhat less will be required in the plant. It has been found that a jar tester most closely parallels the operation of an upflow clarifier as far as chemical dosage and order are concerned.

Summary

In summary, a jar tester can be made to yield a great deal of information on the operation of a water plant but only after considerable effort has been expended in determining just how the tester should be operated to parallel the plant.

III TURBIDITY TESTS

Introduction

Community water treatment plants must firstly produce potable water and secondly esthetically acceptable water (i.e. clear, colourless and with no unpleasant tastes or odours). This latter criterion sets the requirement for the bulk of a water treatment plant since chlorination alone will make the water safe to drink. In Southern Ontario at least, water sources generally have little or no colour and only in exceptional cases is a malodorous water supply used as a source of raw water. This means that the water plant is built to produce clear or non-turbid water. Since the old tires, beer bottles and shopping buggies will settle out easily on standing, the chemical treatment and filter polishing are required only to remove the fine suspended matter (including algae) found in the water; this is turbidity. On the basis of dollars invested in capital and operating costs per pound of material removed, this is the most expensive treatment function performed on water.

Turbidity consists of material ranging in size down to particles so small that they are kept in continuous suspension by collision of the particles with water molecules. This material disperses and absorbs light so that we see a murky solution rather than a clear one. The amount of light dispersion is a direct measure of turbidity and it must be remembered that the amount of turbidity does not necessarily bear any relationship to the weight of the suspended material. Rather the amount (or more accurately, the degree) of turbidity is a function of the particle size, shape and ability to reflect or absorb light. Remember, turbidity is read in units (Jackson turbidity units - J.T.U.) and not parts per million (ppm).

Turbidity may or may not be coloured; if it is coloured it will impart "apparent" colour to the water. The best example is the green colour imparted to some lakes by algae in the water. True colour is dissolved coloured matter in the water such as humic acid which imparts a tea colour. Understandably, colour and turbidity interfere with each other in some instances, each one imparting an artificially high reading to the other. This may be overcome by measuring both turbidity and colour on raw and filtered water samples.

The standard instrument for reading turbidity is the Candle turbidity meter. The operator observes the flame from a standard candle through a sample of water; the deeper the sample through which the candle flame is just indistinct from the background illumination, the lower the turbidity. Removal of one percent of the sample should cause the flame to reappear.

Modifications of the above instrument using a calibrated light source from an opal glass light bulb are more commonly used in water plants and there are some photoelectric instruments which measure the amount of light scattering caused by the suspended matter in the sample. The instruments generally use a fixed amount of sample and vary the light source. The turbidity is read directly off the dial.

COAGULATION AND FLOCCULATION OF WATER - II

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In this second lecture, we again make no attempt to exhaust this subject and the reason is obvious when one realizes that chemical coagulation, using aluminum sulphate, was first employed some 3,000 years ago in China, and only as late as June, 1967, your speaker attended an AWWA Seminar on this subject in Atlantic City, at which it was abundantly shown that we still have so much to learn relative to the scientific principles involved in coagulation, flocculation, sedimentation and finally filtration.

We feel that we have made considerable progress in 3000 years in such matters as method of application of the coagulant, choice of other coagulants besides aluminum sulphate, the improvement of clarification processes by means of mechanical flocculation, improved settling, the use of coagulant aids and particularly, in methods of measuring the results produced and in explaining the principles involved. But even the most advanced expert readily admits that very likely we have more to learn than we already know.

Basic Principles

Why is coagulation, flocculation and sedimentation such an involved and apparently inexhaustible subject? Why is it that some turbid waters can be adequately coagulated with the most simple facilities, employing only a small dosage of aluminum sulphate, whereas other turbid waters require the use of coagulant aids, involved mechanical facilities, and sometimes such seemingly drastic measures as the excess lime method?

To attempt to answer such questions, let us briefly recall the first lecture. In that lecture we established that most surface waters contained a "fog" of turbidity, the particles being merely suspended in the water. We also discussed the fact

that such particles of turbidity generally carried an electrical charge that prevented them from settling in sufficiently short time to be of practical value in the water treatment plant. Particularly, we showed that a "fog" of turbidity would pass through a rapid sand filter relatively undiminished and, therefore, surface waters generally required some treatment prior to filtration.

In that lecture we were able to show that the treatments prior to filtration became known as coagulation, flocculation and sedimentation. Since most of the particles of turbidity in a surface water are negatively charged, we were able to show that the addition of a coagulant resulted in the production in the water of millions of positively charged particles of a metallic hydroxide. We showed that the positive charges on the metallic hydroxide floc particles neutralized the negative charges on the particles of turbidity. This we showed is the act of coagulation.

We further showed that after this initial and virtually instantaneous coagulation had taken place we could, by means of continued slow stirring, cause the floc and turbidity particles to become enmeshed and to grow in size until floc and turbidity become a virtual "snowstorm" of particles that would settle readily, this effect being what we term flocculation. We also pointed out that those particles that did not settle out were now sufficiently large that they could be retained on and in a rapid sand filter.

It all sounds so simple. You have a water containing millions of negatively charged particles, you toss in some aluminum sulphate so as to produce millions of positively charged aluminum hydroxide particles, the particles neutralize each other's electrical charge in a chamber in which we are producing a high speed egg-beater effect. Further on we produce slow stirring by devices not too much different from the dollies in grandmother's washing machine, this slow stirring to permit the floc and turbidity particles to grow considerably in size. Then we resort to settling one of the oldest procedures known to mankind, being employed for centuries in wine making and being used by nature for millions of years in quiescent lakes. Finally, we submit the settled water to filtration through sand, also something that nature has been doing for millions of years.

It all sounds so simple, too simple in fact.

What are the pitfalls? Why do these procedures work so well in some waters, whereas seemingly involved complications of them seem to be required in others?

Some Answers to Problems of Coagulation-Flocculation-Sedimentation

Turbidity - What do we mean by turbidity?

Your speaker has been present at many discussions on turbidity at water works conferences and can state that to date the meaning of the word turbidity has not been fully resolved.

Turbidity to the water works chemist does in fact mean any substance in a fine state of division that on being suspended in water gives the water a cloudy undesirable appearance. So far, so good. Others, including water works chemists, will say that turbidity is any substance or group of substances suspended in water that will prevent, partially or totally, the passage of light through the water.

Your speaker has no quarrel with this reasoning and has noted with approval over the years the improvement in turbidimeters designed to measure the reduction in light transmittance in water due to suspended particles. Some of the later models of these devices are very advanced in design and can and do measure turbidity down to one one-hundredth of a part per million.

While it is very desirable to measure the turbidity in water, starting with the raw water and progressing through the various treatment stages in the plant right through to the finished water, it should be realized that the mere measurement of turbidity is not the complete answer and is not necessarily an end in itself. We are in fact right back to a question that we have just asked - What do we mean by turbidity?

Your speaker saw a mountain stream in Oregon having a turbidity of 20 parts per million. The water plant drawing from this stream had no difficulty in coagulating, flocculating and settling this turbidity by relatively low dosages of aluminum sulphate, requiring no coagulant aid, and did not in fact require mechanical flocculation other than a slight turbulence at the incoming flume. This turbidity was due to the natural weathering

of mountains and was composed essentially of finely divided granitic type substances, very small high-density particles, with a high negative charge on a relatively small surface area.

The Hamilton and Toronto water plants have virtually no difficulty in coagulating the turbidity in Lake Ontario water using only aluminum sulphate. Chicago, however, deriving water from Lake Michigan requires to employ aluminum sulphate, ferrous sulphate and lime, plus activated silica.

The Vaal River at Vereeniging in the Transaal poses an interesting problem. The river rises in an area of such nature that the rocks and soil contribute very little in the nature of dissolved alkalinity or any other mineral substances. The river is quite turbid, and while some of the turbidity is due to clay type substances, most of it is due to organic substances. In such a soft water coagulation was a problem until their research showed that they must first "slightly harden" the water by means of calcium hydrate (lime) and then apply aluminum sulphate plus activated silica.

The Grand River at Brantford has posed some interesting problems. When a laboratory was first established there we found that the turbidity during normal river stages would be composed mainly of diatoms, some soil-like particles, and considerable amorphous organic matter. As long as the turbidity remained below 10 parts per million we had very little of a problem and aluminum sulphate alone sufficed. But flood periods posed a very considerable problem. In the initial stages of a flood the turbidity would rise in excess of 500 parts per million and this turbidity would be composed mainly of coarse soil particles. In this early stage of a flood it was just a case of increasing the aluminum sulphate dose to produce a sufficiently low turbidity on the filters, and in these early stages of a flood aluminum sulphate alone did an excellent job. However, our glory was short-lived, since following the initial stages of a flood we would enter a period of some 10 to 20 days in which the turbidity would be slowly declining from 150 down to 20 parts per million, and during this period the turbidity would be composed mainly of a very finely divided clay derived from the Nith tributary to the Grand. This particular type of turbidity was very difficult to coagulate with aluminum sulphate alone, and often we would be operating at 6 to 8 grains of aluminum sulphate per Imperial Gallon, hoping to keep our finished water turbidity down to one part per million. On such occasions too little aluminum sulphate would

result in a "fog" of uncoagulated turbidity passing through filters, whereas too much aluminum sulphate resulted in a "fog" of aluminum hydroxide particles passing through filters. Due to variable pumpage and variable filtration rates, it was very difficult to adjust to a "just right" dosage of aluminum sulphate.

Use of Activated Silica

Laboratory investigations employing the jar test procedure and a turbidimeter showed two necessities - mechanical flocculation and a coagulant aid, such as activated silica. Mechanical flocculation was employed first and proved of immediate value in the nature of lower finished water turbidity and considerably reduced aluminum sulphate dosages, but even this was not completely successful in periods when the plant was operating above rated capacity.

Finally, activated silica was installed and thus, regardless of whether the river is in normal or in flood stage, we experience no trouble with natural river turbidity. Our investigations have shown that activated silica is the one substance that permits us to operate with relatively high dosages of activated carbon for taste and odour removal. We have time and again proved that aluminum sulphate alone, even when employing mechanical flocculation, will not stop activated carbon from passing through filters in amounts sufficient to cause "black water" complaints. Opposed to our findings at Brantford, Cleveland is able to apply high dosages of carbon and is able to remove same with aluminum sulphate alone, not requiring a coagulant aid - such is the difference in raw waters.

At Brantford, we now regularly apply activated silica in the range of 12.5 parts per million and aluminum sulphate in the range of 2.5 grains per Imperial Gallon (both higher in floods). We feed some calcium hydrate for pH correction, employ flash high speed mixing and slow mechanical flocculation, all resulting in the turbidity entering our filters being in the range of 0.25 to 0.50 parts per million, with the filtered water turbidity so low that it cannot be measured with a Hellige turbidimeter, all this even when the plant is operating at twice the design capacity.

Algae Problems

Before leaving the Brantford example we should mention the subject of algae. Algae are microscopic forms of plant life that abound in surface waters, particularly during warm water periods. Despite the fact that they are a form of life, the sad fact remains that they still turn up as a form of turbidity that must be removed. The literature, and also remarks made at water works conventions, all point to the fact that various types of algae, and there are hundreds of them, do from time to time cause serious filter plugging in water plants.

This would seem to derive from the fact that the various types of algae have a relatively large surface area as compared to their low unit mass, all as opposed to the more usual "mineral" types of turbidity. Thus, it would appear that any charge on an algal particle is spread over a relatively large area. In addition, many of the blue-green algae have an outer gelatinous envelope. Algae are notably difficult to coagulate.

We did some laboratory investigations on the subject in the period 1947-50 soon after the Shand reservoir was built on the Grand River and when the raw water exhibited very high algae counts composed mainly of the blue-green types. By means of jar tests we were able to show that aluminum sulphate very successfully removed "mineral" turbidity, but that it did virtually nothing to remove blue-green algae. By use of a simple magnifying glass, most of the algae could be seen still suspended in the settled water. Some of the algae did naturally settle to the bottom of the beaker, but when a small sample of the total sediment in the beaker was examined under the microscope, it was surprising to find that the algal bodies were in no way attached to or enmeshed in the aluminum hydroxide floc particles. It was merely a matter of coincident settling with most of the algae still suspended in the supposedly clarified water - small wonder then, that algae often plague water treatment plants by coming over on to filters resulting in their early plugging.

This work was repeated many times, but, more important, was also repeated many times employing activated silica as a coagulant aid to the aluminum sulphate.

When the jar tests were run, using activated silica and aluminum sulphate, two important observations became apparent:

1) After settling, the settled water on being examined by a magnifying glass and a turbidimeter proved to be truly clear and no free floating forms of algae were in evidence, the activated silica, aluminum sulphate floc having taken down all of the algae bodies.

2) When the sediment from these activated silica-aluminum sulphate jar tests was examined under the microscope, an entirely different picture was presented - no longer did we find that algal particles had coincidently settled with aluminum hydroxide particles, merely "setting alongside" the floc, but, rather, we found that the algae bodies were now truly embedded in the activated silica-aluminum sulphate flocs. These activated silica-aluminum sulphate flocs containing the embedded algae bodies did, under the microscope, present the appearance of a fruit dessert in which various fruits are embedded in a gelatine dessert.

Algae should not arrive at the filters, and when they do they cause trouble in filter plugging. Some jar test experiments employing activated silica or other coagulant aids are indicated.

<u>What is Turbidity?</u>

From the above discussion it should be obvious that we can now answer our original question as to why it is relatively simple at some water plants to clarify a water by means of aluminum sulphate alone, with the minimum of mechanical equipment, whereas in other water plants it is necessary to employ other coagulants, to employ coagulant aids, and to become involved in the use of high speed flash mixers and mechanical flocculation. The answer is that the substance that we loosely term turbidity is not one true substance, but may be many substances and the nature of these substances will vary from one raw water to another and may, in some instances, vary in the same raw water seasonally, and in critical cases may vary from day to day.

We have only mentioned turbidity, but there are other factors that tend to influence the ease, or otherwise, that a water may be coagulated.

Realizing that "turbidity" can be any one or all of the following: clay, silt, soil, finely divided rock particles, various species of algae, organic matter, activated carbon and so on, it is also just as important to realize that just as turbidity substances vary from water to water, so do the pH, alkalinity, and dissolved mineral contents of these waters vary.

Importance of pH, Alkalinity and Dissolved Solids

Regardless of the type of turbidity that we must remove, our results will be greatly influenced by the nature of the raw water itself in respect to pH, alkalinity and total dissolved solids.

Let us select one type of turbidity, clay, and select a concentration of 50 parts per million, and on finding this type and magnitude of turbidity in waters varying in pH, alkalinity and total dissolved solids, let us see what happens:

If the water is low in pH, it will generally not take as much aluminum sulphate to do the job as compared to a higher pH water, because in addition to providing aluminum hydroxide floc particles the sulphate radical produces acid to lower the pH to the point at which coagulation is at an optimum.

Low pH raw waters would therefore seem to be ideal. However, if low pH is also coincident with low alkalinity we may run into trouble because there is not enough alkalinity present to react with the aluminum sulphate to bring about suitably rapid coagulation. This is generally overcome by the addition of some alkali such as calcium hydrate or sodium carbonate prior to the addition of the aluminum sulphate.

To remove 50 parts per million of clay turbidity having negative charges on each particle requires a commensurate number of aluminum hydroxide particles having a positive charge. Now, in a low pH water to obtain the required number of aluminum hydroxide particles we are inadvertently adding a considerable amount of unrequired acid in the form of the sulphate radical. We had to add

this acid, otherwise we would never have been able to get the aluminum originally into solution. Therefore, in coagulating low pH waters we find that they tend to become much lower, often too much lower, in pH, requiring adjustment of pH later by means of calcium hydrate or sodium carbonate.

High pH and high alkalinity waters also have their advantages and disadvantages.

The high pH can be so high that we must add far more than normal dosages of aluminum sulphate so as to take advantage of its pH reduction brought about by the sulphate radical, but this can give us trouble in finding that we now have too much positively charged aluminum hydroxide present. Our originally negatively charged clay particles are down in the settling basins, where they should be, but the water entering the filters is now loaded with a host of unwanted positively charged aluminum hydroxide particles which are just as undesirable as the original turbidity and these particles will pass through the filters, giving a turbid effluent.

Just as low pH, low alkalinity waters can be given some pre-treatment prior to the addition of aluminum sulphate, an alkali being employed, so can a high pH, high alkalinity water also be given some pre-treatment prior to the addition of aluminum sulphate, and we find that sulphuric acid is often used for this purpose.

One of the great advantages of activated silica as a coagulant aid is that it considerably broadens the range of pH over which aluminum sulphate successfully operates, thus reducing the necessity of pH and alkalinity adjustments prior to coagulation.

Someone is going to say: "Oh, well, in the case of high alkalinity waters you are not plagued by the water becoming too acid and, therefore, you do not require to adjust pH and alkalinity later" --- nothing could be farther from the truth. High alkalinity waters are generally alkaline because of the presence of calcium bicarbonate and sometimes magnesium bicarbonate and, in some instances, both of these alkaline salts. These bicarbonates react quite readily with aluminum sulphate, so you will find a rapid production of aluminum hydroxide floc. But the sulphate radical reacts with these calcium and magnesium bicarbonates resulting in a production of calcium and magnesium sulphate in solution. In doing this, carbon dioxide is released from the bicarbonates.

This released carbon dioxide does not escape from the water, but stays in solution as carbonic acid. It passes right through the plant to attack cast iron water mains resulting in corrosion and red-water complaints. The higher the turbidity the more aluminum sulphate is required, the higher the natural bicarbonate alkalinity, the more carbonic acid is produced in reaction with the aluminum sulphate and, therefore, more corrosion and red-water complaints are in evidence.

It may come as a surprise to realize that even when the water leaving the plant has a pH of 7.8 (which is in the alkaline range) and also has an alkalinity of 175 parts per million, that it is possible for over 60 parts per million of carbonic acid to exist in the water to cause corrosion, this carbonic acid having been formed in an all times alkaline water due to the acid sulphate radical. The answer to this problem is to add sufficient calcium hydrate to the water just after coagulation with aluminum sulphate has been initiated and prior to filtration. Classically, the resulting pH should be adjusted to pH 8.3 at which point free carbonic acid will not exist, but in actual practice adjustment to the range pH 8.0 to 8.5 will suffice.

We originally asked the question - Why is the turbidity in some waters more easily coagulated than others? We have found answers to this in the fact that there is no one substance that represents turbidity, but that the term turbidity encompasses a whole host of substances varying in particle size, density, surface area, charge on the particle and chemical composition. We have also partially answered our original question by showing that these various types of turbidity may be suspended in waters of varying pH and alkalinity, all of which will influence coagulation.

Other Factors Affecting Coagulation - Flocculation

Have we come to the end of the road, or are there other factors that can influence coagulation? There are other factors that influence coagulation and it is possible that there may still be others that we have not yet discovered.

Most chemical reactions proceed more rapidly and more efficiently at higher temperatures and, therefore, the warmer the water the more rapidly will coagulation be accomplished. Some natural organic substances in water have been said to tend toward inhibiting good coagulation.

Detergent phosphates present in modern packaged detergents have been definitely shown to seriously and adversely affect coagulation at the water treatment plant. These phosphates are added to the packaged detergent mixture as "builders" and they do a number of very useful jobs in the industrial and domestic laundering of textiles. One facet of their usefulness is that they "decoagulate and deflocculate" dirt and prevent it from staying in the fabric. After their job is done they generally pass right through the sewage treatment plant ending up in our raw waters, making life unhappy for water plant operators who are not interested in decoagulation and deflocculation, but who require to do some very positive coagulation and flocculation. Generally, the presence of these phosphates calls for increased aluminum sulphate dosages, an added expense, and generally, they result in a less desirable form of floc.

At Brantford we have conducted considerable investigations into this phosphate problem. To cut a very long story short, we were able to show that there is a "slow-time" reaction between the phosphate and aluminum sulphate and that the problem can be neatly sidestepped by shortening the time between the addition of the activated silica and the aluminum sulphate so that an activated silica-aluminum hydroxide floc can form before the phosphates attack the aluminum sulphate. Even so, the presence of the phosphates still require more than the usual dosage of coagulant.

The concentration of dissolved solids in the raw water will affect the rapidity and success of coagulation. Generally, when a chemical reaction takes place in which a part of the reacting chemicals is to be thrown out of solution (in our case aluminum hydroxide), the reaction will proceed more rapidly if the solution already contains considerable dissolved solids. At the Rand Water Board, Vereeniging, South Africa operation, the dissolved solids content became of prime importance. The turbidity was high, but the dissolved solids content and alkalinity was low. They added calcium hydrate (lime) to bring the pH and alkalinity up so that the aluminum sulphate would have something to react with, but, just as important, they found that the calcium hydrate addition had to be high enough to raise the dissolved solids content to the extent that it would aid in forcing the aluminum hydroxide out of solution. They could have employed a number of chemical salts for this purpose, such as sodium sulphate or even common table salt, but there was no point in employing two or more chemicals when calcium hydrate successfully did both jobs of raising the alkalinity and the total dissolved solids content.

Dissolved solids are generally measured by evaporating a sample of water and weighing the resulting mineral residue. At Vereeniging they found that this could be more conveniently done on a constant monitoring basis by means of electrical conductivity measurements and now their calcium hydrate additions are made strictly on the basis of electrical conductivity.

At least, we have attempted to answer our original question as to why the turbidity in some waters is more readily coagulated than in some others. We are not so brash as to suggest that we have found all the answers, or that we ever will.

Current Research - Zeta Potential

Is there any research being conducted to find more answers to these problems? - very definitely, yes.

One has only to mention zeta potential to draw attention to possibly the most important factor being studied in the entire field of coagulation. Zeta potential deserves, in itself, a number of detailed lectures. Stripped down to utmost simplicity the zeta potential is essentially concerned with the electrical charge on particles in suspension in an aqueous solution. In other words, is there a negative or positive charge and, if so, what is the magnitude of such charge on that little speck of turbidity in your raw water and how best can we neutralize such a charge.

In essence, a sample of the raw water containing turbidity is placed in a specially constructed cell. The apparatus is designed in such a manner that it is possible to impose high voltage direct current electricity through the water in the cell. Wiring and switches are so arranged that the direction of the flow of direct current may be from left to right or vice versa. A microscope is included so as to observe the moment of particles in the electrical field. A graduated scale permits the timing of the speed of the particles and from this may be derived the magnitude of the charge on the particles. Knowing the direction of the direct current applied, and observing the direction of travel of the particles, discloses whether the particles are negatively or positively charged and, of course, if they do not move at all when the current is on they can be said to not carry any charge.

In addition to studying the charges on natural turbidity particles in water, it is also possible to take a sample of the water from which all natural turbidity has been removed and then to study the nature and magnitude of the charges on aluminum hydroxide and ferric hydroxide floc particles produced in the water by coagulation.

The next natural step is to take some of the original raw water containing the natural turbidity, coagulate it with the appropriate coagulant and then to note the nature and magnitude of the electrical charges on the resulting coagulated turbidity-floc particles. Obviously the research is directed to ensuring that the positively charged aluminum hydroxide and ferric hydroxide floc particles produced by chemical coagulation will more adequately neutralize the negative charges on the natural turbidity particles, the final aim being that all resulting particles have a zero charge since it has been shown that they will settle more readily than those particles that still retain some charge. Obviously, the effect of the various coagulant aids are being studied as part of this research.

Much of this original research has been done on synthetic turbidities in synthetic waters - fundamental research to establish basic principles - this must always come first. More lately, this work is progressing into the study of natural turbidities in natural waters. Some of the larger water works have started to employ zeta potential measurements in the study and control of coagulation.

It all sounds so advanced, but your speaker has it first hand from one of the leaders in this research, that it may well be over fifty years before we can junk the time-honoured jar tests and even then they may still have to use jar tests in conjunction with zeta potential measurements.

New research is being done in regard to the filterability index. The better a water is coagulated, flocculated and settled the better it will filter on the basis of a given bulk of water passing through a given filter in a measured unit of time.

Mention has already been made of the more advanced and certainly more accurate turbidimeters.

Do not let these new advances confuse you. When all of these new developments are ready for the field, you and your plant will be ready for them. If you are from one of the smaller water plants, do not waste your time feeling envious of some of the larger water plants that can afford these new areas of research.

Above all, please realize that you and your plant, and the very large ones also, can get along very nicely with present tried and true relatively simple methods - jar tests, pH, alkalinity, simple turbidity measurements etc.

By these relatively simple methods you can successfully control coagulation and flocculation in any raw water in any water treatment plant on this planet.

These simple procedures are detailed in the American Water Works Association's Laboratory Manual M-12. If at first you feel that you are experiencing difficulty in understanding these procedures, do not fail to ask others in the water works profession, including the technical personnel of the Ontario Water Resources Commission.

Conclusions

In the primary lecture, we said that there were no golden rules, each raw water having its own peculiarities that show up differently in differing water plants. We have emphasized this statement in our discussion of different types of turbidity in waters of varying chemical composition. What you will require to do in the nature of coagulation and flocculation at your plant on your raw water may turn out to be worthless at another plant on another raw water and, of course, the opposite may be true.

We would, however, leave you with this final thought -- it is possible to coagulate, flocculate and settle out any turbidity in any raw water on this planet if you follow a few simple concepts, employing relatively simple equipment, and providing that your water plant has the necessary wherewithal and capacity to duplicate the results that you have accomplished in the test equipment. Research of the highest order,or of the simplest,is of little value unless you have the plant to match it, although such research does point to the necessity of plant improvement and expansion.

LEAK DETECTION

and

PIPE THAWING

John P. Dawson, Manager

Dunnville Public Utilities Commission

LEAK DETECTION

Water leakage has been said to cost $50 million dollars a year in U.S.A. but it has been larger by all reports because the cost of water goes up each year. Every industry has losses which are not large enough to cause any real problem and the water industry is no exception. It has been accepted in a well managed system amounting to from 10 to 15 per cent for leakage alone. A.W.W.A. sets a rule of thumb for leakage in a new main at 250 gallons per 24 hrs. for each inch per mile. On an eight inch main, three miles in length, allowable leakage is 8 x 250 or 2,000 gallons a day per mile for 6,000 gallons for the three mile pipe.

As waterworks men, you should set a good example not to waste water at home, but this good example does little good if your system has losses that make the amount you save almost too small to notice. In Ottawa, it was estimated that loss from 18 leaks amount to 604,000 gallons a day; however, one split main leak was more than one half of the total loss. The amount of money which was lost amounted to $152,000 annually. We had a split main that accounted for 250,000 gallons a day and it was being lost directly into a storm sewer. Another storm sewer leak was located when we were looking for the first one, and it had been caused by a contractor who had built the water main into the outer wall of a storm sewer.

There are two main methods of finding leaks and these two methods may be divided into results of leaks that you can see and leaks you can hear. Use your common sense and it will tell you that if you sink up to your ankles in mud in a dry section of ground, there must be water somewhere and it should be checked if you have a water main or service nearby. Just because the surface ground is dry is no proof that you do not have a water leak. Water will find the easiest path to escape

and sometimes this path is not the obvious one of bubbling up through the surface. This is particularly true during the winter when it is cold and nasty and as most of you men know, leaks almost always happen when it is cold and nasty, usually dark. Now to divide the two types of leaks - what to look for:

Leaks You Can See

1. Water flowing on the ground.
2. Damp sections of land that don't dry up.
3. A very nice patch of green grass in the middle of a lawn that is dry.
4. When it is snowing and one section of the ground does not have any snow on it. The water leaking raises the temperature of the ground slightly and melts the snow.

A real leak in winter time results in a ring of ice forming around the leak. This usually happens on a roadway. In the winter time when the ground is frozen, the water from the leak will travel quite long distances to find a spot where the frost is not solid. We had a main leak in the winter and our first call came from a man two hundred feet from the leak who reported water running in his basement. We found the water bubbling up under his front steps and then we found his service would not shut it off; we finally traced it back under the pavement and down three houses, and there was a six inch main split right around.

Leaks You Can Hear

If you are listening for a leak, try to remember the big leaks are quiet, and the little leaks sound like Niagara. As mentioned before, all water lines are allowed to leak a little, and slight leaks that don't get any bigger can be tolerated, but little leaks have a habit of washing sand into the leak and the sand wears the leak larger and eventually you have trouble, so don't neglect the leaks because they are small.

There are two methods of listening for leaks and both work sometimes. One uses an ordinary metal rod or stick with an ear cap on its end. You place the end of the rod or stick on any water carrying pipe and listen. Some people are very expert at this simple procedure because they have used it often enough to be able to identify the sound of the leak as opposed to the sound of real usage. The modern electrical amplifying equipment accomplishes the same result, but it allows more volume and is often equipped with a meter to give

visible indications. The equipment if moved from area to area usually using a hydrant as a listening post as opposed to a dog's purpose for a hydrant and where the noise is loudest, try to locate on curb boxes or lawn taps, the closest area. It may be possible to shut off services at curb boxes and limit the area under question.

This all seems fine, but in practice someone tells you about the water long before you start your survey. The really bad leaks are the ones going into sewers or sand that carry the water away without it being noticed. If you have a bad leak you must start by finding the general area by means of shutting down mains and this must be done at night. You would suspect such a leak when your pumpage suddenly increases and doesn't drop below a certain level at night or Sunday when it normally would. We had one leak that was equal to one quarter of all the water we pumped, and yet it made no sign on the ground. It was quiet and luckily the ground was frozen or someone would have fallen in the hole it washed out under the surface.

PIPE THAWING

Incidence of Freezing Problems

Frozen water services and mains comprise the major winter operational problem in many cities of Canada and the Northern United States. Freeze-ups occur frequently enough in most municipal water systems in Ontario to require the services of a thawing crew, if not on a full-time basis, at least on a call basis, during winter months. A few municipalities in Southern Ontario experience 300 or more frozen services each winter. Other northern communities consider these figures commonplace.

In the Arctic, special designs are necessary to ensure water circulation. At Fairbanks, Alaska, water is warmed, then pumped at three feet per second through wood-stave mains and twin copper service lines. This system operates in ground which freezes to depths up to ten feet in which the soil at six feet is as cold as 15 degrees Fahrenheit.

Factors which Affect Soil Temperature

1. Air temperature: and other meteriological factors such as: precipitation, sunshine, relative humidity, wind velocity dewpoint, and barometric pressure.

2. Surface cover: snow and vegetation reduce frost penetration and slow its retreat in spring;
   - pavement increases frost penetration and accelerates its retreat in the spring;
   - dark surface colours increase absorption of <u>solar</u> energy.

3. Soil and topography: type of soil - a granular soil has a greater frost penetration than a fine-grained cohesive soil;
   - moisture content of soil-density of soil-organic content of soil-concentration of salts-soil structure.

From the above considerations on the flow of heat in soils, it becomes apparent that so long as a favourable balance of heat is maintained in a pipeline, freezing conditions will not develop.

Frozen services are more common than frozen mains. Less water volume and longer periods of no motion are characteristic of services. It is known that insulation of pipes provides considerable protection from freezing. Materials such as wood, plastic, or possibly glass have been used. Provision of a pipe enclosed within a pipe to provide an air space would provide a solution, albeit an expensive one. The solution - Bury the pipes below the frost line.

<u>Methods Used in Thawing of Water Mains</u>

The real problem which concerns us here today is "What do you do when pipes do freeze?" Let's leave the problems of pipe design and heat transfer to the designing engineers.

Frozen water lines require the application of some external source of heat whereby the heat transferred will be sufficient to melt the ice and to permit flow. Many methods have been used:

- digging down to the pipe and building a fire in the trench over it;
- using gasoline torches;
- wrapping pipe in rags and pouring on hot water;
- using steam;
- use of electricity.

Other than the use of electricity, these measures involve considerable time, inconvenience and are often messy. Pipes can be split from extreme heat when steam or

open fire is used. This is not an attempt to minimize the problems associated with electric resistance thawing. These problems, which are many will be discussed later.

Electrical Thawing of Water Mains and Services

Simply, the electrical thawing of pipes may be stated thus: the passage of electrical current through a conductor whether it be a wire or pipe line encounters resistance. This resistance creates heat, the intensity of which depends on the characteristics of the conductor.

The following tablesgive pertinent pipe thawing data:

Metal	*Relative Resistance OHMS per Mil. foot	Approximate Melting Point degrees Fahrenheit
Copper	9.35	1900
Steel	63.00	2600
Wrought iron	82.80	2800
Lead	123.00	625
Cast iron	684.00	2500

*Resistance in piece of metal 0.001 in. in diameter and one foot long.

Conditions Affecting the Thawing of Frozen Pipes by Electricity

Diam. of pipe in.	Pipe Material	Resistance OHMS	Length ft.	Approx.* Volts	Amp.	Min. Time	Size B&S	Amp
3/4	Wrought Iron	82.80	600	60	250	5	Size of	
1	Wrought Iron	.....	600	60	300	10	leading wire	
1½	Wrought Iron	.....	600	60	350	10	to use.	
2	Wrought Iron	.....	500	55	400	15		
3	Wrought Iron	.....	400	50	450	20	0	200
4	Cast Iron	684.00	400	50	500	60	00	225
6	Cast Iron	.....	400	50	600	120	000	275
8	Cast Iron	.....	300	40	600	240	0000	325
3/4	Copper	9.35	400	40	500	30		
1	Copper	.....	400	40	600	60		
1¼	Copper	.....	300	35	600	60		
	Steel	63.00						
	Lead	123.00						

*The lowest possible voltage should be used.

The melting points shown above indicate the danger of melting lead service pipes with high currents. Cast iron heats most readily, while copper, a good conductor heats slowly. Whenever lead goose-necks are used, regardless of the materials used in the remainder of the service, low rates of current should be used to protect the lead.

Thawing Procedure

1. Isolate the frozen section of pipe.
2. Include the frozen section in an electrical circuit by connecting cables from the source of energy to the closest convenient points in the piping system. Make sure you don't include yourself in the circuit.

   (a) When thawing mains connections can be made to hydrants, curb service boxes, etc.

   (b) For house service pipes connections can be made to exposed pipes in the house and the service stop.

3. Ensure that good electrical connections are made; remove rust scale at the point where the clamp is to be fastened to the pipe. Otherwise arcing may cut holes in the pipe.

4. If a house service is involved, remove the water meter from the circuit to break connection between the service pipe and the house piping.

5. Remove the ground clamp from the water pipe to prevent stray currents getting into the neutral wire and into the house wiring system.

6. Proceed with thawing.

Removal of the meter alone or disconnection of the ground clamp alone is not sufficient assurance that current will not be fed back into the house wiring circuits. Underground contact of metal pipes or some other chance circuit may occur.

Some do's and dont's

1. Use least current possible to accomplish job.

Do not hurry by using high currents. The lower the voltage, the less chance of injury to persons and property including piping appurtenances.

2. Avoid connections which might waste current and prolong the thawing job. Use only generator sets equipped with meters in order to determine the exact amount of current used. If the ammeter does not indicate a current flow, this may be caused by:

(a) Poor connections or bad joints in pipe; or
(b) Connections that have been made to different pipe systems.

Make sure the frozen length of pipe is included in the circuit.

3. Avoid possibility of shorts or grounds. Current might be fed back through gas services via the water heater. No gas pipes, furnace support wires, etc., should be in contact with the pipe being thawed. Radio ground wiring should be detached. Lead gaskets in gas meter couplings can be melted if care is not taken. Heat may be detected by placing the hand on the meter couplings. To play safe, the main house switch should be disconnected.

4. Make certain of the pipe material in use and make allowances in the current applied.

5. Make sure that wires from energy sources are adequate and that good electrical contacts are afforded. Scraping of the pipe surface may be required. Distance between connections should be as short as possible.

6. Open the pipe before thawing. This will let you know when water is beginning to flow. It avoids the possibility of steam pressure developing.

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